The AMERICAN PHYSICS TEACHER

VOLUME 7 FEBRUARY, 1939 NUMBER 1

Observations on the Objectives and the Teaching of Physics in England and Canada

JOHN SATTERLY
Department of Physics, University of Toronto, Toronto, Canada

SCHOOL PHYSICS

THE objectives in teaching physics in the schools usually are to encourage the student to observe the physical phenomena of the world around him, to carry out experiments —both qualitative and quantitative—in order to get first-hand knowledge of the processes underlying the natural phenomena, to correlate the processes under "laws," to check these laws by further experiments, and to learn to formulate (and assimilate) the theories which these laws support. The student is taught how to think and reason in such a way that he may have confidence in his own deductions.

One thing it is hoped the student will learn is that disobedience to nature (or to God) means ultimate disaster, that nature expects the truth, and that although he may occasionally mislead his teacher, and even himself, there is no prospect of doing that to the All-Knowing. The student also learns that while infinite accuracy in experiment and statement is unattainable by mortal man, different degrees of accuracy are possible; and that one can be trained not only to obtain a "result" from an experiment, but also to state its degree of accuracy or error.

Lastly, the student is trained to take his place in society when he grows up, and in many cases how to obtain his living.

Teachers of physics exist because of the necessity and desire of the world at large to train students toward these objectives, and because to many grown-ups the teaching complex is an "urge" which takes them to these pleasant but nonremunerative paths of life. Pupils need teachers and the born teacher is not happy without students.

I do not wish to say much on the subject of school physics, because I am unfitted for the task of making judgment; but as a university teacher I have naturally a great interest in the way the students are prepared before they reach me.

The Canadian student, and I speak more especially of the Ontario student, has been supplied for many years with good textbooks of Canadian authorship for the whole of his upper school life. For the earlier years of the upper school a textbook is prescribed and for the last year another textbook, although not compulsory, is almost invariably used. Both books are by Professor Chant, of the University of Toronto, and Mr. Merchant, of the Department of Education of Ontario. They have been continually brought up to date by additional help from younger men selected because of their proficiency as teachers.

My criticism of the Ontario system is that the hours allotted to physics are not enough to allow the pupil to assimilate all that he learns, and too much is left to mere memory. The two books together total about 1000 pages and the time allotted is five 40-minute periods per week, this to include any laboratory work. The work is covered in two or three years and is read much too fast, so fast that the knowledge does not really become a part of the student's make-up.

Especially is this true for schools that have little or no apparatus, although, of course, the absence of apparatus gives more time for the working of examples. Of the American system of teaching physics, I know nothing. I gather that good textbooks of the same type as the Ontario books are in use and I hope more time is given to this subject.

One small point about textbooks concerning which I am doubtful is the policy of inserting photographs and biographies of eminent physicists, and photographs of power plants, factories, bridges, airships, of radium and x-ray applications, etc. The personal photographs usually show the physicist as an old man and teach the student nothing except that he was an Englishman or an American or a German, and that he is to be extolled accordingly. The photograph of an engineering triumph usually does not show anything of note except its size; its working cannot be explained or followed; and although the student may learn that physics has a cash value in the world at large, it is more important for him at this stage to get hold of the fundamental truths of physics. One physical principle may explain the working of half a dozen machines but even half a dozen machines will not necessarily teach the student one law of physics.

The trend in the Canadian educational field at present is to lessen the specialized teaching of one or more sciences and to encourage the teaching of general science. This applies especially to those students who will leave school at the age of seventeen years to enter the world at large.

It is 40 years since I left my English school and things have changed greatly. I was at an old grammar school in a small country town. There were only 60 boys and four masters, so we could get individual attention. We were not bound to any system of outside examinations. The headmaster was a pioneer in the teaching of science and, having picked me out for a scientific training, had me do little but mathematics, physics, chemistry and agriculture for about my last three years at school. I think my attainments at leaving were about the same as those of a good average boy turned out in, say, 1938.

The average weekly form work was eight to nine 1-hour classes in the sciences, plus two 2-hour periods in the chemistry and physics laboratories, respectively, and one afternoon a week on the school farm.

We used different books for different branches of the subject and read the subjects leisurely and concurrently for years. The books used were of the Glazebrook and Maxwell type for physics, Roscoe, Newth and Remsen for chemistry, and Hall, Knight, Stevens, Loney and Edwards for mathematics. I had read quite a bit of calculus before leaving school.

Secondary schools in England are of so many different kinds, that it is hard to say what amount of science is done. There are the great public schools (we should, on this side of the Atlantic, say very private schools), the ancient and endowed grammar schools, the county and city municipal secondary schools, and the smaller private schools, leaving out the municipal technical schools, works schools and other vocational schools. I shall deal only with the second and third types.

The policy prevailing in England allows considerable liberty to the masters and pupils in the selection of textbooks. One advantage of the separate textbook for the separate subject is that it can be discarded more readily if a better book appears. Incidentally it gives the pupil a smaller armful of books to carry around.

In 1918 there was published a report of the committee (Chairman, Professor J. J. Thomson) appointed by the Prime Minister to inquire into the position of natural science in the educational system of Great Britain. In its long report of 86 foolscap pages the Committee deals with all kinds of schools and all kinds of pupils. It discusses the position of science as a whole and also the individual sciences in the school system, and makes recommendations, many of which have been put into practice. Some of the recommendations are as follows.

In the four age years 12 to 16 there should be at least 3, 6, 6, 6 periods a week given to the sciences (physics taking one-third). Laboratory work need not necessarily be done by all pupils. Many experiments are better performed by the teacher with larger apparatus. Certainly the laboratory work should not be like "drill." It should follow closely the book work. For students of ages 16 to 18 who are specializing in science, not more than two-thirds and not less than half the time should be given to science. Calculus should be taught to all students specializing in mathematics, physics and chemistry. The teachers should have a sound knowledge of the

scientific background and a wide outlook on life; they should be encouraged to do a little research, and separate rooms at schools should be provided for this purpose.

Recommendations are also made for the general scientific teaching of those students not proceeding to the university. Here the applications of science, the effect of science on the life of the community, and the history of science are emphasized. Special recommendations are also made for those schoolboys who are specializing, or who are preparing to specialize, in the professions—medicine, engineering, agriculture, pharmacy, etc.

A typical school-leaving examination is that of London Matriculation. There are five subjects and six 3-hour papers, all of which must be passed at the same examination. They are English, elementary mathematics (two papers), and three papers selected from the sciences. For this purpose physics is given in three papers—mechanics, heat, light and sound, electricity and magnetism—but not more than two may be taken. Having passed this examination or its equivalent at the age of seventeen, many stay on at school and pass the next examination—the Intermediate Examination of the University of London. They then need spend only two years at the University to win the degree. This course, although popular for a while, is not now favored; it tends to immaturity of the student.

As in Canada, there is in England at present a movement to popularize the teaching of general science in schools. This usually means a smattering of all the branches with accurate thinking in none. Starting in girls' schools, where a little knowledge of botany was at one time considered "genteel," it has spread by a general atmosphere of laziness to boys' schools; and textbooks are now being poured out to cope with the demand. Many of the older teachers deplore this new attitude, and I agree with them that any one subject thoroughly well done gives the better education.

Nature of June 18, 1912 reports an interesting lecture given by Sir J. J. Thomson before a meeting of science masters on "The functions of Lectures and Textbooks in Science Teaching." Regarding the scribble some students take down in lectures, Thomson says:

> A textbook must be quite exceptionally bad if it is not more intelligible than the majority of notes even of good lectures. It may be good training to reduce one set of such notes to sense and logical order, but there are so many lectures in the universities that the reduction of notes takes too much time and none is left for independent reading.
>
> The objective of lectures is to rouse the enthusiasm of the student so that he will look up information for himself. A lecture ought to be interesting and to arouse interest; dullness should be the unpardonable sin. The lecturer should avail himself of the "purple" patches of the subject, emphasize the fundamentals, and discuss the ideas and assumptions.

The same is, of course, true of the schools.

Thomson also pointed out that closer contact is got in tutorial classes but that these should not be used just for solving difficulties. Let the student puzzle for awhile; the teacher should throw in a word occasionally, cross-examine and draw the students out, and redirect them if he sees they are following a wrong path.

Small laboratory classes are best; the instructor then has time to talk to the individual student, and the experiments can be trials of strength. When laboratory classes are large, instructions full, and experiments foolproof, the work is a mere routine of taking readings and the student is not called upon to think.

One good feature of recent years is the increasing mathematical attainments which boys bring to the university. The elements of the calculus should be taught in school to all boys who are to take science in the universities.

Thomson does not agree that all the examiners in university courses should be internal. Teachers should not be hampered by syllabuses or methods; the trustees should get a good man and let him do his best. In results he need not fear an outside critic.

University Physics

Most of the universities of England are quite modern. Oxford and Cambridge stand in a class by themselves, both being formed of a close grouping of well-endowed residential colleges. The science work of these universities is done by the university as a whole, whereas the nonscientific work is largely done by the colleges within their own walls.

The University of London is also in a class by itself. It is a loose-knitted body of many colleges in and around London, some of which were of university rank long before their federation, which occurred in 1903. Before that time the University was an examining body only. Its examinations were of high standing and, as they were open to all without restrictions of nationality or religion, the degrees were much coveted; in fact, many graduates of Oxford and Cambridge who wanted degree standing of a higher standard of academic work than that of their own universities worked for London degrees. Since federation, the University of London has had two sets of examinations and degrees: one is on the "external" side, a continuation of pre-federation days; the other, on the "internal" side, is carried out within the federated colleges. Naturally there is a close coordination of syllabus, examiners and papers.

In the provinces there are universities at Manchester, Birmingham, and other large centers. These have grown out of the University Colleges which, before they received their own charters, gave work for the London degrees. They are staffed largely by Oxford and Cambridge men because of the "kudos" of the two older universities. The examinations at all the universities are now pretty much standardized, both for entrance and degree requirements.

Financially, Oxford and Cambridge are well endowed and self-supporting, receiving government grants only for special work, such as some particular agricultural research, cold-storage problems, aeronautical research, and so on. London and the other universities receive government and municipal grants in proportion to their needs. Fees are higher in Oxford and Cambridge; but scholarships are numerous and few students reading for honors need stand entirely on their own resources, nor is it necessary for them to work at odd jobs during the summer. Since the war of 1914–1918, practically all educational work in England has been vigorously promoted; money has been given fairly freely so that several universities have been almost rebuilt and there has been no cutting of salaries. The English professorship is still a profession and not like so many professorships on this side of the Atlantic, which are practically trades in which men have to slave and supplement their earnings by outside work in order to get a decent living.

The degree course in England is usually of three years duration, the students arriving at about 18 or 19 years of age.

At Cambridge the students taking the Natural Science Honor Tripos[1] select four subjects out of seven, physics being one. These are read for two or three years, and success in the examinations together with the three years of residence secures the B.A. degree. This is called Part I of the Tripos. A further year at one subject—for example, physics—leads to Part II of the Tripos. There are also Pass courses leading to the General degree.

In the other universities there are Pass and Honor courses. The University of Toronto, a typical Canadian university, requires three years attendance for a Pass degree and four years for an Honor degree. The Toronto B.A. degree in Honor mathematics and physics compares very favorably with an English degree in the same fields. A good feature of an Honor course is that the student is in a fairly homogeneous group working on a carefully balanced lecture and laboratory course leading to the degree. The class receives the best the university can give and from it come our best teachers, and men for postgraduate work and the higher grade of business research work. In Toronto we have about 50 students entering the first year and about half that number will complete the degree.

Physics in the University of London

It may be of interest to describe the course in physics at one of the English universities, and I will take as a fair example the course at the Royal College of Science in London. This purely science college was founded by the Prince Consort (the husband of Queen Victoria) to develop the teaching of science and scientific methods in England. Later it became associated with the Royal School of Mines and, since 1903, has also been linked with the City and Guilds (of London) Engineering College. The three, collectively, are known as the Imperial College of Science and Technology and form a constituent college of the

[1] The Tripos is the name given to the degree examinations because in the olden days the candidates sat on three-legged stools and wrangled with the examiners.

University of London. Thomas Henry Huxley was one of the deans and its professors are always of the highest standard. I was a student there in 1898–1901 and had as professors Sir Norman Lockyer (astronomy), Sir William Tilden (chemistry), Sir Arthur Rücker and H. L. Callendar (physics), John Perry (mathematics and mechanics), J. W. Judd (geology), and Sir William Abney (color). They were pupils of such men as Lord Kelvin, Sir J. J. Thomson and Sir Charles Lyell; it was an inspiration for a young man to listen to them. The best of the professoriate took the first-year classes—a good plan which I think should be followed everywhere. It is a mistake to turn a young lecturer loose on elementary classes; he demands too much and is often impatient. In the early days the Royal College of Science was designed to train teachers, and little research work was done except by the head professors. The courses were designed accordingly, one strong feature, at least in physics, being that much of the apparatus the student used in his first-year work was made by him and used in class. He could take it away as a part furnishing of the school laboratory to which, in the normal case, he proceeded. In those days apparatus houses were not as common (nor apparatus as standardized) as they are now.

Doctor J. H. Brinkworth has kindly supplied me with the following details of the *present* courses leading to the Associateship in Physics in The Royal College of Science. The length of the session is about 30 weeks and the hours, 10 to 5 with an hour off for lunch. The weekly program is:

First Year[2]

First half: chemistry, 21 hr; mathematics, 9 hr.

Second half: physics, 20 hr; mathematics, 10 hr.

The physics consists of 3 hr of lecture, 2 hr of class work, 12 hr of laboratory classes, and also 1 hr of lecture and 2 hr of laboratory work in astrophysics.

Second Year

First half:[3] physics, 9 hr (3 lec., 6 lab.); mathematics, 4 hr; mathematical physics, 4 hr; graphics and geometry, 8 hr; mechanics, 5 hr.

Second half:[4] physics, 25 hr (4 lec., 1 class, 20 lab.); mathematics, 2 hr, physical chemistry, 3 hr (optional).

Third Year

Physics, 23 hr (5 lec., 18 lab.); mathematics, 3 hr; private reading, 4 hr.

The physics lectures in the first year deal with: heat, 10 hr; light, 10 hr; and electricity and magnetism, 20 hr. An elementary knowledge of mechanics, practical mathematics and mechanical properties of matter is assumed.

In the second year the lectures deal with: physics applied to chemistry, 40 hr; elasticity, wave motion, and sound, 20 hr; magnetism and current electricity, 20 hr; general physics, 50 hr; wave theory of light, 20 hr; electrostatics, 8 hr.

I submit here a memorandum from Professor H. S. Gregory (who has charge of the second-year laboratory work) on the aim of the practical work and the actual experiments performed in the session 1937–1938.

The students are encouraged to take an interest in laboratory practice quite apart from the interest associated with examinations. They are allowed to suggest and carry out modifications in regard to existing experiments. The latter aspect is assisted by problems so arranged that both the theoretical and experimental considerations are carried out entirely by the students themselves. This more recent development has been very successful and has resulted in great keenness and enthusiasm. The student is, in this way, trained to regard himself as an investigator and not merely as a candidate for the degree.

The course of lectures dealing with the various subjects has been arranged in such a way that the fundamentals receive first claim, and great care is taken always to supply a mechanism on theory of action whenever possible; as an example, in the lectures on osmosis, the theories of osmosis are considered first, then less important details obtained through private reading on the part of the student, and any experimental details, as part of the laboratory course. Great stress at this stage is laid on a sound knowledge of the kinetic theory of gases as being of first importance.

My experience is that students always wish to be interested, and that any failure in this respect is caused by the lecturer himself. Often too little time is spent on the details of presenting a lecture.

The development of the second-year laboratory course is along lines that will enable the student to be equipped either for an industrial career or for research in pure physics.

[2] This first year of work is common to all students, no matter in what subject they intend to specialize later. Details of the procedures for the first-year physics and astrophysics experiments appear in two instruction books of about 180 and 80 pages, respectively, published by the college.

[3] This work is done largely in common with students specializing later in mechanics.

[4] Geology (done in common with students specializing later in geology) may be substituted for the morning work in physics; this leaves 9 hr of physics laboratory work.

First Half-Session, Second-Year Laboratory

The first half-session is confined mainly to instruction in the use of instruments:

Adjustment of various types of galvanometers; investigation of the sensitivity;

Adjustment and calibration of electrometers; determination of capacitance and application to measurement of small currents;

Measurement of high and low temperatures;

Production and measurement of vacuums; determination of the speeds of vacuum pumps;

Laws of heat conduction in metals and in poor conductors.

Second Half-Session, Second-Year Laboratory

The work in the second half-session is arranged in conjunction with the various courses of lectures, and is divided into sections of which the following are examples:

Vacuum practice:—properties of rarefied gases, molecular streaming; radiometer action; construction and use of low pressure manometers, including automatic indicating instruments; use of vapor pumps.

Magnetism:—use of strong magnetic fields to measure para- and dia-magnetism; transformation temperatures of ferromagnetics; experiments involving the use of liquid oxygen.

Viscosity of gases:—effect of temperature on viscosity between −183° and 600°C.

Construction and use of electric furnaces:—measurement of high temperatures from aspects of resistance and thermoelectricity; effect of temperature on the elastic properties of various substances.

Use of Relay Circuits for various purposes, such as the more accurate measurement of time.

Use of Electrometers in investigations of piezoelectricity, pyroelectricity, ionization of gases, and polarization in solutions of electrolytes.

Heat conduction:—hot-wire method with gases; effect of accommodation in heat conduction; thermal conduction in metals; thermal conduction in liquids and insulators.

The third-year lectures consist of: geometrical optics, 12 hr; sound, 12 hr; alternating circuits and electromagnetic theory, 20 hr; atomic theory, 30 hr; quantum theory, 8 hr; thermodynamics, 20 hr; magnetism, 6 hr; and spectroscopy, 20 hr. In the laboratory the students are instructed in the use of instruments of the greatest sensitivity and precision. The list below (supplied by Professors Moon and Gregory) shows the experiments performed in 1937–1938, selected, of course, from a fuller list given in the calendar.

Third-Year Experiments, 1937–1938

Long Experiments:

Refractive indices (spectrometer)
Refractive indices (gases, Rayleigh)
Fabry-Perot interferometer
Electron charge (Millikan)
Thick lens (principal planes, foci, etc.)
Specific heat of copper at low temperatures
Measurement of capacitance in emu (ratio of units)
Experiments with total-radiation pyrometer
Characteristics of valve amplifier
Characteristic curve for photographic plate
Calibration of microphone
Absorption curves for x-rays in various metals
Microscopy (in Technical Optics department)
Calibration of weights; sensitivity of balance

Short Experiments, Set 1:

Jamin refractometer
Michelson interferometer (adjustment; coincidences between the sodium lines)
Infra-red spectrometer
Kelvin bridge (low resistance)
Anderson bridge (inductance)
Measurements of frequency by bridge method
Dynamometer calibration and use
Characteristics of electric motor
Characteristics of transformer
Characteristics of copper-oxide rectifiers; use as instrument rectifiers
Camera lens (chromatic and spherical aberrations, astigmatism, coma, field curvature)
Alternating-current potentiometer

Short Experiments, Set 2:

Elementary polarization experiments
Optical rotation (quartz)
Twyman and Green interferometer
Stellar interferometry (double-slit method)
Visual acuity
Experiment on "random distribution"
Vacuum, gas filled, and copper-oxide photoelectric cells
Characteristic curves for triode valve
Valve oscillator
Electrical resonance
Critical potentials
Properties of thyratron

About 10 periods of 2 hours each at approximately equal intervals throughout the session are assigned to test papers set by the respective lecturers.

The foregoing course leads to the Diploma of the Associateship of the Royal College of Science and also suffices for the B.Sc. Degree in Honor Physics at the University of London.

Special advanced courses are also given in spectroscopy, 20 hr; spectroscopic laboratory

work, 20 hr; physical instrument design, 30 hr; applied optics, 120 hr; microscopy, 18 hr; instruments, drawing and workshop, 180 hr; photoelasticity, 24 hr. Postgraduate courses leading to higher degrees—such as the Diploma of the Imperial College, and the M.Sc., Ph.D. and D.Sc. degrees in physics at the University of London—each occupying full time for one session are given in technical optics, optical designing and computing, applied geophysics and meteorology.

In my time (1898–1901), as previously mentioned, we made much of the simple apparatus used in Part I Physics. We made a glass scale, specific gravity bottle, optical lever, thermometer, monochord, dropping plate apparatus, grease spot photometer, wire gauze grating, astatic galvanometer, simple cell, Wheatstone bridge, potentiometer, one-ohm coil, and high resistance (graphite on ground glass). In elementary astrophysics we photographed spectra, made a sextant and an astronomical telescope with Huygens eyepiece, and surveys of the grounds with plane table, theodolite, and compass. In Teachers' Refresher courses we made a platinum thermometer, Callendar and Griffiths bridge, moving coil galvanometer, Pohl commutator, lantern slides, and colored diagrams.

I gather from a recent prospectus that the manufacture of apparatus has now been almost discontinued, the course having been increased by the insertion of more difficult experiments. The student in Part I Physics must, however, provide himself with files, pliers, drawing instruments, India ink, dusters, magnifying plate, box of weights (50 gm to 1 mgm), beakers, funnels, tubing, evaporating basins, Bunsen burner and tubing, retort stand, tripod, and wire gauze. A man from a supply firm comes around twice a week and a student must replenish his supplies. This encourages him to be careful and to put his apparatus away in his locker before leaving the laboratory. I wish we could do the same thing in Toronto.

Physics in the University of Bristol

Professor A. M. Tyndall of the University of Bristol has kindly supplied me with details of what is done at Bristol.

The hours are 9 to 5 daily. The Pass degree course consists of three years of postmatriculation work in three subjects. The physics portion involves 4 lectures a week and about 9 hr of laboratory work.

The Honors degree course consists of two years of the Pass course augmented by work in the special honor subject—for example, physics—and one year devoted to the honor subject alone. In this year lectures are given in: differential equations of mathematical physics; heat and thermodynamics; magnetism, electromagnetic theory of light, electrical oscillations, and thermionics; optics, quantum theory, classification of spectra, and photoelectricity; x-rays and crystal structure; electrical conductivity; and modern views of atomic structure, wave mechanics, radioactivity, and nuclear structure.

Professor Tyndall adds:

> The practical work in the graduating year consists of a relatively small number of experiments of a somewhat searching character. For instance, it is not uncommon for a man to take several full days of six hours each to complete a given experiment. We feel that this is better for the students than to continue during the last year with the general type of stock experiments that they get in previous years. Although these experiments may differ from year to year, the following is the list for the session just past:

Part II

Random errors (special plate)
Vacuum gauges
Rydberg constant (concave grating, mercury arc, hydrogen tube, panchromatic plates)
Banded spectrum (spectrometer, Fabry plates, mercury arc)
Fabry-Perot interferometer: (1) fine structure, (2) Zeeman effect (plates, C.D. spectrometer, neon tube, mercury arc, magnet)
Subsidiary maximums, plane grating (optical bench, grating, graded slit, lenses, sodium vapor lamp)
Michelson interferometer
Decay of thorium emanation
Range of particles
Measurement of *e* (Millikan)
X-rays, sodium chloride lattice
Ionization and critical potentials
Susceptibility of cobalt solution
Characteristics of machines

> In addition to this, all Honor Physics students carry out a special concentrated three-weeks' workshop course involving lathes and other machines, carpentry, and glass blowing.
>
> As to textbooks for Honors Part II, I think one can take the Methuen Monographs as a general sort of basis.

Physics in the University of Toronto

In Toronto the work in the Honor Mathematics and Physics course, with specialization in physics in the third and fourth years, is, expressed in hours per week:

First Year

Heat, mechanics, and properties of matter, 3 hr of lecture and 3 hr of laboratory; chemistry, 4 hr; mathematics, 7 hr; extra subjects,[5] 4 hr; problem papers in physics and mathematics to be done at home.

Second Year

Light, sound, electricity and magnetism, 3 hr of lecture and 6 hr of laboratory; mathematics, 7 hr; mechanics, 2 hr; extra subjects,[5] 3 hr.

Third Year

Heat, properties of matter, electrical potential, and electron tubes, 6 hr of lecture and 6 hr of laboratory; mathematics, 2 hr; mechanics, 3 hr; astronomy, 2 hr of lecture and 2 hr of laboratory; extra subjects,[5] 3 hr.

Fourth Year

Lectures on thermodynamics, physical optics, polarized light, series spectra, electromagnetic theory, conduction through gases and radioactivity, advanced acoustics, elementary quantum theory, and mathematical operations in physics, 9 hr; laboratory work, largely in spectroscopy, x-rays, thermionics, and electronics, 9 hr; extra subjects,[5] 2 hr.

It will be noted that in the English universities more time is given to laboratory work than in Toronto. This means that the work there is continuous over longer periods; the student usually has his own bench and locker, with tools and other accessories; and he may stick at an experiment for a long time and thoroughly master it. This method is better than that used in Toronto, in the first three years at least, where experiments for the larger classes are assigned for three-hour periods and have to be completed —well or badly—so that the next period of the class will be free according to the prearranged schedule.

Conclusion

I have attempted to describe the work in physics in the English universities and at Toronto. The American teacher knows of American conditions and is thus able to make comparisons. I myself cannot do so, unfortunately, but I believe the work is about the same caliber the world over. So much depends on entrance requirements and the choice of the students, and here the English universities may have the advantage. The English university year is also more spread out—with longer holidays at Christmas and Easter, which gives the student more time for private reading.

While the Canadian student rarely does any academic work from May until October, Cambridge requires every student reading for honors in the sciences to put in six or seven weeks of laboratory work in the summer (the "long vacation" term). This means only three or four hours in the morning, enough to keep his mind on the work, the afternoon and evening being spent in a more delightful manner. I do know that the Canadian student comes back "very rusty" in October and almost a couple of months are needed to pull him back to the position he was in the preceding May.

I conclude with a word on lectures and notebooks. Textbooks are much the same the world over. The chief publishers push their wares in every market and the choice of suitable textbooks for any particular class and year is overwhelming. Most of the books are good; we feel we couldn't write better ones. Personally I prefer the special to the general textbook; it is less to carry and a change is more easily made. One point to consider is whether students buy the books or borrow them; and if they buy, do they keep them or dispose of them as soon as the examination is over. In Toronto the students prefer to borrow. If they do buy they usually sell; most of the textbooks the students use seem to have passed through many hands.

I have already quoted Professor J. J. Thomson on the relative merits of lecture notes and textbooks. I usually employ a textbook that suits my subject matter, specify the pages we shall be reading, and beg and implore students to attend to me and not waste time taking notes. In most cases, however, one might be talking to a stone for all the notice they take of the request. The habit of note-taking is ingrained.

As regards laboratory notebooks, the time spent on them by the students is deplorably long. Whenever possible I use printed instructions (two to four pages) which are distributed to the

[5] The extra subjects are scientific French and German, religious knowledge, ancient history, philosophy, etc.—a peculiar survival of early Toronto legislation.

students at the beginning of the laboratory period. These contain references to textbooks, and full descriptions of the apparatus and method of carrying out the experiment. The students are asked to paste these in their notebooks, and not to enter their readings on the printed pages, although skeleton tables are usually shown there. If the experiment is not often done or is advanced, typewritten instructions are provided. Although the students are required to make only an abstract of the typed matter, they find it easier to copy it in full and the instructor cannot persuade them to do otherwise.

In some classes the students take their laboratory record books home and write up the experiments at leisure. With medical, dental, and similar elementary classes we are now insisting that the books be written up in the 3-hour class period and left behind as the students leave the laboratory. Time is also saved by putting on the laboratory bulletin board the list of next day's experiments or even giving out the printed instructions ahead of time so that the students can read them in advance.

In all cases the notebooks are corrected, marked, and returned in time for the next day's work. In marking we endeavor to correct and help the student where he goes wrong. The demonstrator who is just beginning his job is apt to do this part of the work very poorly. For one thing he is usually starting research in his non-teaching time and grudges every moment he takes off to look after the students (though this is what he is paid for); moreover, he does not know enough to make a good job of it, but just goes on perpetuating the errors of which he himself has never been cured. A common error with students is to carry out the arithmetic of their calculations to an absurd length. We try to cope with this fault by having a special problem class on calculations and errors. We implore the students to use contracted methods, or four-figure logarithms, or the slide rule; but the school teaching in this branch of work is usually very poor, and I am sure many students think they can make up for bad experimentation by long-winded arithmetic. In fact, it usually takes more than a year to train a student in this branch of the work and, unless he is kept to mark the next year, he is as bad as ever two years afterwards.

Diagrams of apparatus also seem to give trouble. While some students are artists and have to be restrained from embellishing their diagrams, others cannot draw at all. In Toronto we have recently sent our third-year honor men to the drafting department in the Engineering School to learn lettering and careful and accurate draftmanship. Their work is much improved thereby and, when they come to publish a research, the professor will not have to redraw their diagrams in a state fit for publication.

Students should be enjoined to consider their laboratory work as a privilege. The experiments are set in order to train them in coordination of hand, eye and ear, as well as to help fix the knowledge gained in lectures and reading. We as teachers do not set the experiments to become aware of the values of the physical constants they are planned to measure. We know them already. We want the student so to discipline himself that he can carry out a technical job by himself and speak the truth in his written record.

References

Report of the Committee (Appointed by the Prime Minister) to Enquire into the Position of Natural Science in the Educational System of Great Britain (His Majesty's Stationery Office, London, 1918).

Report of an Enquiry into the Conditions Affecting the Teaching of Science in Secondary Schools for Boys in England (His Majesty's Stationery Office, London, 1925).

The Teaching of General Science, The Science Masters' Association (John Murray, London, 1936).

A History of the Cavendish Laboratory, 1871–1910 (Longmans, Green, 1911).

J. J. Thomson, *Recollections and Reflections* (Bell, 1936) and James Clerk Maxwell, *A Commemoration Volume, 1831–1931* (Cambridge Univ. Press, 1931) contain many interesting remarks on the early and modern teaching of physics both in lectures and in the laboratory.

Genius begins great works, labor alone finishes them.—JOUBERT.

Hans Christian Oersted—Scientist, Humanist and Teacher [1]

J. Rud Nielsen
Department of Physics, University of Oklahoma, Norman, Oklahoma

OERSTED is known to the world as the discoverer of electromagnetism. In Denmark he is remembered with equal gratitude as a great teacher and exponent of physical science, and as the founder of the Royal Technical College and other institutions which have contributed to the enlightenment and welfare of the country. His greatness, not least as an educator, depended on the fact that his interests extended over the entire range of human culture. He was a humanist as well as a scientist. "None of our scientists," he was once told, "regard art, science and men from such a comprehensive point of view as you." The wide scope of Oersted's writings makes them valuable as source material for anyone who wishes to familiarize himself with the status of physical science and philosophy in the early part of the nineteenth century.

Education

Hans Christian Oersted was born in 1777 at Rudkøbing in one of the smaller Danish islands. His early education was rather irregular. The wife of an old German wigmaker taught him to read and to write; the wigmaker taught him German and as much arithmetic as he knew himself, namely to add and to subtract. Multiplication he learned from an older boy and division, from the parson. A former university student taught him Latin and other subjects, and the town judge gave him and a one-year younger brother lessons in French and English. In addition, the brothers "seized with avidity all other means of gaining knowledge. . . ."[2] From his eleventh year Hans Christian helped in his father's pharmacy; and the laboratory work together with the reading of chemical books early aroused his interest in natural science.

In 1794 the two brothers went to Copenhagen to prepare for admission to the University, which they entered the following year. Both of them soon became ardent exponents of Kant's new critical philosophy. Hans Christian heard lectures on mathematics and physical science; his brother took up law and later became a famous jurist. They led a studious life and lived together in *Elers Collegium*, in the very rooms in which the writer of the present article lived more than a century later. The poet Oehlenschläger described them as follows:

> As in a dim monastic cell the Oersteds sat here, grave, silent, at their studies. . . . To all their fellow students they shone resplendent like the Dioscuri, and even ripe scholars soon noticed what was in them.

In 1797 Oersted graduated as a pharmacist with high honors. The previous year he had won the university gold medal for an essay on esthetics. He was awarded the same prize, in 1798, for a medical paper on the origin and function of the amniotic fluid. In addition to the two prize essays, he published in 1798 two "Chemical Letters." In the opening paragraph of the first of these, he wrote:

> I promised . . . to give you an account in letters of the systematic parts of chemistry. . . . I keep my promise with pleasure, both for your sake and for that of science, which you know I find so much pleasure in communicating to others.

This desire to write for the general public stayed with him all his life, and there were few years when he did not write one or more popular papers. In the same year, Oersted wrote the first of many essay book reviews. These were

[1] This article is based largely on Oersted's collected scientific papers, edited by Dr. Kirstine Meyer, née Bjerrum, and published in 1920 by the Royal Danish Academy of Sciences and Letters, under the title *H. C. Ørsted, Naturvidenskabelige Skrifter*, ved Kirstine Meyer f. Bjerrum (Andr. Fred. Høst & Søn, Copenhagen). This work, consisting of three large volumes, contains also two essays by Doctor Meyer. The first of these, entitled "The Scientific Life and Works of H. C. Ørsted," is printed in English; the other, dealing with Oersted's varied activities in the Danish commonwealth, is in Danish. The first two volumes contain 61 scientific papers of which only nine are in Danish. The second volume contains, in addition, 66 papers (in Danish) read before the Royal Danish Academy of Sciences and Letters. In the third volume are reprinted some 50 popular papers on physical science (in Danish). The work does not include Oersted's textbooks, nor his philosophic and poetic works. The writer is indebted to the Danish Academy of Sciences and to Professor Martin Knudsen of the University of Copenhagen for kindly placing this and other material at his disposal.

[2] Since most of the sources quoted are Danish, no detailed references are given. All of the quotations are from the writings of Oersted or his contemporaries. The writer of this article is responsible for the translation of most of them.

rather lengthy and, as he explained, written "in such manner that they have a content of their own, i.e., that they may be read with interest and profit independently of the books which they review and appraise."

In 1798, a new journal was started in Copenhagen for the purpose of promoting the Kantian philosophy, and Oersted became a member of the editorial staff. He contributed a paper on Kant's *Metaphysical Foundations of Natural Science*. This was elaborated into a dissertation, written in Latin, for which, in 1799, he won the degree of Doctor of Philosophy. The thorough study of the critical philosophy gave Oersted a sharp sense for systematic thinking and formed an excellent background for his later scientific work, although it made him an opponent of the atomic theory for the greater part of his life. In these early writings Oersted displayed a great enthusiasm for physical science and a remarkable power to express himself in clear and elegant language.

First Teaching Experience and Physical Research

It was now time to look for a position, and Oersted had his heart set on an academic career. The prospects, however, were far from good. In fact, the state of physics at the University of Copenhagen was a sorry one in those days. Physics had been a subject in its own right since the beginning of the sixteenth century. However, when Pietism flourished in the early part of the eighteenth century, the chair of physics was discontinued to make possible an expansion of the divinity school. Physics was taught by the professors of mathematics or medicine. In 1800, the medical professor who had taught physics and chemistry died, and Oersted, who was then substituting as manager of a well-known pharmacy, applied for that part of the position which concerned physical science. The patron of the University, the Duke of Augustenborg, and several of the older professors were opposed to Oersted because of his advocacy of the newfangled Kantian system; but the pressure of his many friends was so strong that he was finally appointed "adjunct," without salary, with the duty of lecturing two hours a week to the pharmaceutical students. This was hardly an enviable position, but Oersted accepted it with enthusiasm and apparently added a lecture and a laboratory for graduates. Laboratories were then unknown in Denmark, as in most other places, and Oersted could arrange the laboratory only by using the facilities and space of the pharmacy which he managed.

In the year 1800 Volta constructed his galvanic pile, and with its aid Nicholson and Carlisle discovered the electrolytic decomposition of water. This stimulated Oersted's first physical research. He constructed a small battery of novel design and invented a gas voltameter, by means of

Oersted as a young man. [From a copper-print made by Crétien, Paris, 1803.]

which, he said, "we shall be able to measure galvanism even more accurately than electricity." He also discovered that "syrup of violets" is stained green by the negative and red by the positive electrode, and found that the colors disappear on shaking. He did not follow up these observations, either for lack of time or because he did not fully recognize their importance.

Travel Abroad

In 1801 Oersted, then nearly 24 years old, received a traveling fellowship and set out on a trip to Germany and France which lasted two and a half years. Although not all the influences to which he was subjected on this journey were of equal value, the trip was of great importance for his later scientific work. He traveled by wagon from town to town, visiting universities, factories, mines and museums. Wherever there was an opportunity he attended lectures, worked in laboratories, or "galvanized" with the small battery that he carried with him. In Berlin he associated mainly with the philosophers, Fichte, A. W. Schlegel and his brother Friedrich, and made a thorough study of Schelling's philosophy of nature. Although he was not blind to the dangers of the romantic movement, which he recognized more clearly later, he was deeply influenced by it. In Oberweimar and, later, in Jena, Oersted visited Ritter who shortly afterwards discovered the electrolytic polarization. Ritter and Oersted became close friends and performed a number of galvanic experiments together. Ritter was a clever experimenter and the creator of several rather fantastic theories that appealed to Oersted at the time. During his first stay with Ritter, Oersted became acquainted with a book obscurely written in Latin by the Hungarian chemist, Winterl. Its leading idea, namely, that all the forces of nature arise from the same fundamental causes, appealed greatly to Ritter and Oersted. They succeeded in showing, to their own satisfaction, the connection between electricity and heat, light, and chemical effects; but with magnetism they had difficulty, although the researches of Coulomb pointed to a fundamental similarity between electricity and magnetism. Oersted decided to adapt Winterl's work for German readers. His book was published in 1803 under the title *Materialien zu einer Chemie des neunzehnten Jahrhunderts*. It was not well received, especially outside Germany where the romantic philosophy of nature had not penetrated; and its publication caused Oersted some embarrassment after his return to Denmark.

In 1802 Oersted went to Paris, where he stayed more than a year. Although he missed the philosophic atmosphere, he gradually learned to appreciate the high development that physical science had reached there. He published two papers on Ritter's galvanic discoveries and did his best to secure for Ritter a large prize offered by Napoleon. He attended lectures and made detailed notes, not only of their contents, but also on their form:

> I learn here daily much about the art of lecturing: from Charles, the way lectures should be delivered; from Vauquelin, how they should not be delivered. . . . I realize how much I have lacked of this art, or rather that I have not known it at all; but when I have completed the training I have now begun I hope to return the wiser. . . .

About Cuvier's lectures he writes:

> These belong to the most interesting of those I have had opportunity to attend. It is the philosophy of natural history that he is here occupied with. . . . It is the spirit of science that he depicts. . . . As to his delivery, it is fluent and beautiful without being embellished with the empty rhetorical phrases of the French.

About Berthollet he writes:

> He speaks with difficulty and hence somewhat slowly; but this very manner fits well the profound ideas that he teaches.

Oersted was enthusiastic about the *École Polytechnique*, especially about the student laboratories:

> The mere dry lectures such as they are given in Berlin without the art of experimentation do not please me; for, after all, all scientific advances must start from experimentation.

Teaching and Textbook Writing

In January, 1804, Oersted returned to Denmark. The enthusiasm for the romantic philosophy of nature revealed in his writings had not pleased the University administration, so he had no hope of obtaining a salaried position. An influential friend advised him to go into applied chemistry, but he replied that while he would be glad to lecture occasionally on technical problems, he was primarily interested in pure chemistry and physics, and rather than seek financial success he would live in accordance with his ideas. After obtaining charge of a collection of physical and chemical instruments belonging to the king, he issued a printed invitation to private lectures on physics and chemistry for which he charged admission. These lectures were a great

success, and the attendance increased from year to year. In 1805 he writes in a letter:

> My lectures on chemistry are so strongly attended this year that not all could find room. These lectures are also attended by five or six ladies. You will readily imagine that I make no change in my lectures for their sake.

In another letter, he says:

> These lectures are attended by women as well as by men, although I have only five women. As an introduction to these lectures, I gave in the first three hours a survey of the difference between the older and the newer status of physics. These three lectures were open to the public. My lecture room was far too small to hold all who desired to come, and I won much applause. . . .

A student who attended Oersted's lectures a few years later described his way of lecturing in the following words:

> He usually began very quietly with a few observations and instructive remarks; sometimes also with derivations and definitions of particular terms, whereby he wished to make sure that he would be understood when he proceeded further; once in a while he would also pause to discuss the translation of chemical or physical terms into the Danish language. He then pursued a definite series of phenomena and ideas which were closely related to each other and to the definitions first given. In the beginning his lecture was distinguished almost solely by sharp reasoning, but little by little the separate objects united into larger groups and these in turn joined into a greater unity which he presented vividly to our imagination. Thus his speech became ever mightier, like a stream which grows and is joined by many tributaries, and finally it acted with such a power that at least the younger ones, who were not yet bound by preconceived notions and were susceptible to the new and unusual in his delivery, could with difficulty resist him.

The success of these private lecture courses could not fail to impress the University administration, and in 1806 Oersted was appointed *professor extraordinarius* in physics with the duty to examine candidates in philosophy and to teach physics and chemistry to medical and pharmaceutical students. Although the salary was miserable, Oersted was happy: "I obtain hereby the privilege of being able to found a school of physics in Denmark, for which I hope to find some talented persons among the many young students I shall now have."

With Oersted's appointment, physics was again recognized as a science in its own right rather than merely as a service discipline for medicine and pharmacy. However, only after a long struggle did this recognition become more than a gesture. Oersted worked out detailed proposals for a reform of the study of physics, but they were shelved by the administration. In one of these plans he mentions that on a trip abroad he had made a study of the influence which the experimental sciences had upon a country's welfare. He continues:

> The first question I asked myself was if the chemists and physicists really are right when they claim that their science has such an important influence upon the welfare of the state and if the conviction which I had myself in this regard was based on sufficiently solid reasons. I found that this question must really be answered with a "Yes!" In a country where the scientific knowledge has really penetrated there is soon formed among all educated people a clear idea of what science is able to do and what must be left to practice. . . . But the most important advantage of the diffusion of chemistry and physics among all classes is this, that the practicians acquire theory. . . . If the value of the experimental sciences is considered solely from the point of view of national economics, it may be said that the state needs theorists only to teach the practical people those parts of the theory which are most important to them and to enrich science with new theories which always, sooner or later, will be useful to the practicians.

With his great ability as a writer and his interest in teaching, it was natural that Oersted should write several textbooks. His largest work, *The Science of the General Laws of Nature, Part I*, which appeared in 1809, dealt with the mechanics of solids and fluids and with sound. A second part was to treat "chemical physics"—heat, electricity, magnetism and optics, in addition to what we now call chemistry; but it was never completed, although several of the subjects were treated in separate books. *Part I* appeared in several editions and was used in Denmark for more than fifty years. According to the preface, it was written in such a manner that it could be used both by beginners and by advanced students:

> It is my wish and in part my hope that the students who once, through this work and through my lectures, have acquired a good background in physics should continue this study during the rest of their lives and use this book, with the aid of which they have made their first step in science, as a companion on their further path. . . . I readily admit that I have not

labored for those who merely wish to obtain the knowledge necessary to earn their daily bread in some position.

The introductory chapter, entitled "General Remarks about Science," although now naturally out of date, is vastly superior to the corresponding chapter in most present-day textbooks. In this introduction, as in many other places, Oersted emphasizes the importance of studying the history of science. "By such a study . . . one gains an insight into the development of the whole human mind. . . ." An interesting feature of this book and of several later writings is Oersted's attempt to coin short and natural Danish words to take the place of awkward foreign terms. Many of his new words, such as "ilt" for oxygen (from "ild" = fire) and "brint" for hydrogen (from "brænde" = burn), have become a permanent part of the Danish language. In the preface, Oersted promised to publish an annual supplement in order to bring the book up to date. Time did not permit him to keep this promise. Instead, he delivered, for the rest of his life, a monthly lecture devoted to recent advances in physics and chemistry.

Oersted also wrote papers on the teaching of science with titles such as "On the Manner in Which a Textbook of Physics Should be Written," and "The Briefest Way of Presenting the Theory of Electricity through a Series of Experiments." In this connection it may be mentioned that he, some years later, invented a peculiar grading system (with the scale, 8, 7, 5, 1, −7, −23) which is used in Denmark to this day.

In 1815, the king presented his collection of physical instruments to the University, and increased appropriations were made available for experimental work. Oersted spared no efforts to add to this collection and to find the best available quarters for it. It was of the utmost importance both for his research and for his teaching. Once he wrote in a letter: "I have now beautiful instruments and can fortunately make any experiments whatsoever." In connection with the problem of housing the instrument collection, Oersted succeeded in establishing the first chemical laboratory at the University of Copenhagen. At first, this laboratory consisted merely of a kitchen, but it had the grand name of Royal Chemical Laboratory. A few years later,

Oersted in 1822. On the table stands the compass needle; in his hand is a metal disk on which an acoustic figure is formed; in the background may be seen an early form of his piezometer and also a large galvanic battery. [From a painting by Eckersberg.]

Oersted's pupil, W. C. Zeise, the discoverer of mercaptan and xanthogenic acid, became the first Professor of Chemistry. Oersted's growing reputation as a scientist and his remarkable ability as a lecturer gradually broke down the disfavor with which he was looked upon by the administration and, in 1817, he was made *professor ordinarius* and member of the governing board of the university.

Scientific Work

Oersted's teaching load was heavy and for many years economic difficulties forced him to add to his income by extra work. At times he was discouraged, but somehow he managed to continue his experimental and theoretical researches. There are indications that his teaching gave him stimulation for scientific work. Thus he begins one paper with the words: "My physical researches go in part parallel with my lectures." On the other hand, he began many very promising investigations which his other duties prevented him from carrying to completion.

In 1807 he finished an extensive and important investigation of acoustic figures to which he was led by the hope of finding electrical effects accompanying the oscillations. The introduction to his paper contains this interesting reference to Chladni:

> It follows from the infinity of nature that no observer can discover all that is in an experiment. To understand an experiment quite completely would be the same as finding the key to all of nature. Hence one cannot reproach the ingenious discoverer of the acoustic figures if he has not observed all that really lies in his experiments.

The last part of the paper consists of philosophic speculations on the "profound incomprehensible reason of nature which speaks to us through the flow of music." These ideas were later elaborated in a paper, "On the Cause of the Pleasure Produced by Music."

In 1812 Oersted went abroad again, spending more than a year, mainly in Berlin and Paris, It is interesting to note that he is now rather critical toward the German romantic philosophers about whom he was so enthusiastic in his youth:

> It is also my firm conviction . . . that a great fundamental unity permeates all nature, but just when we have become convinced of this it is doubly necessary that we turn our attention to the world of the manifold where this truth will find its only corroboration. If we do not, unity itself becomes a barren and empty thought leading to no true insight.

On this trip he completed a theoretical work on chemistry which was first published in German and shortly afterwards adapted for French readers under the title, *Recherches sur l'identité des forces électriques et chymiques*. The main conclusion of this book is that all chemical affinities, as well as heat and light, are produced by the positive and negative electricities. The book was well received but, because of its philosophic form and the qualitative nature of its many ingenious observations, it is difficult to ascertain what influence it had. Oersted is still true to his Kantian convictions in opposing the atomistic theory. An interesting feature of the book is the development of an electrical wave theory of light which was elaborated in later papers.

Oersted's researches in the next decade covered a wide range of fields. Volta, and later Simons, had obtained results that seemed to disprove Coulomb's inverse square law for electrostatic forces; so Oersted repeated Coulomb's experiment. He verified the inverse square law for moderate distances but found deviations from this law for very small and very great distances. However, he apparently was not quite convinced about their reality. In the years 1818 and 1819, he investigated the minerals of the island of Bornholm and, in 1820, he discovered the alkaloid piperine.

THE DISCOVERY OF ELECTROMAGNETISM

The belief in a connection between electricity and magnetism had taken a firm hold of Oersted's mind during the time of his association with Ritter. It was nourished by his study of the romantic philosophy of nature, although this philosophy otherwise retarded rather than furthered his scientific development. In 1808, Oersted had proposed the problem of the relation between electricity and magnetism for the prize essay of the Danish Academy. In his *Researches on the Identity of Electrical and Chemical Forces*, he had attempted to show that the magnetic effects are produced by electricity; but, as he later put it himself, "he was well aware that nothing in the whole work was less satisfactory than the reasons he alleged for this." In 1817, he constructed, together with Esmarch, a large galvanic battery of small internal resistance with which he made a number of electrolytic experiments. No remarkable results were forthcoming until in April, 1820, when, during an evening lecture, he discovered the effect of an electric current upon a magnetic needle. In the *Edinburgh Encyclopedia*, Volume 18 (1830), Oersted gives the following account of his discovery:

> Electromagnetism itself was discovered in the year 1820 by Professor Hans Christian Oersted of the University of Copenhagen. . . . In the winter of 1819–20, he delivered a course of lectures upon electricity, galvanism and magnetism before an audience that had been previously acquainted with the principles of natural philosophy. In composing the lecture, in which he was to treat of the analogy between magnetism and electricity, he conjectured that if it were possible to produce any magnetical effect by electricity, this could not be in the direction of the current, since this had been so often tried in vain, but that it must be produced by a lateral action. This was strictly connected with his other ideas, for he did not consider the transmission of electricity through a conductor as an uniform stream but as a succession of

interruptions and re-establishments of equilibrium in such a manner that the electrical powers in the current were not in quiet equilibrium but in a state of continual conflict. As the luminous and heating effect of the electrical current goes out in all directions from a conductor which transmits a great quantity of electricity, so he thought it possible that the magnetical effect could likewise eradiate. The observations, above recorded, of magnetical effects produced by lightning in steel-needles not immediately struck confirmed him in his opinion. He was nevertheless far from expecting a great magnetical effect of the galvanical pile; and still he supposed that a power sufficient to make the conducting wire glowing might be required. The plan of the first experiment was to make the current of a little galvanic trough apparatus, commonly used in his lectures, pass through a very thin platina wire which was placed over a compass covered with glass. The preparations for the experiments were made but, some accident having hindered him from trying it before the lecture, he intended to defer it to another opportunity; yet, during the lecture, the probability of its success appeared stronger, so that he made the first experiment in the presence of the audience. The magnetical needle, though included in a box, was disturbed; but as the effect was very feeble and must, before its law was discovered, seem very irregular, the experiment made no strong impression on the audience. It may appear strange that the discoverer made no further experiments upon the subject during three months; he himself finds it difficult enough to conceive it; but the extreme feebleness and seeming confusion of the phenomena in the first experiment, the remembrance of the numerous errors committed upon this subject by earlier philosophers, and particularly by his friend Ritter, [and] the claim [i.e., demand that] such a matter has to be treated with earnest attention may have determined him to delay his researches to a more convenient time. In the month of July, 1820, he again resumed the experiment, making use of a much more considerable galvanical apparatus. The success was now evident, yet the effects were still feeble in the first repetitions of the experiment because he employed only very thin wires, supposing that the magnetical effect would not take place when heat and light were not produced by the galvanical current; but he soon found that conductors of a greater diameter give much more effect, and he then discovered, by continued experiments during a few days, the fundamental law of electromagnetism, *viz., that the magnetical effect of the electrical current has a circular motion round it.*

On July 21, 1820, Oersted announced his discovery in a paper entitled *Experimenta circa effectum conflictus electrici in acum magneticam*, which was sent to learned societies and scholars in the various European countries. An English translation appeared in Thomson's *Annals of Philosophy* (London, 1820). In this paper, which is rather too brief to be perfectly intelligible, Oersted describes some of his experiments and gives a simple rule for finding the direction of the force upon the magnetic pole. In stating his findings he says that the effect passes through all the various mediums which he placed between the conductor and the magnet, and that the force depends upon the nature of this medium, as well as upon the distance from the conductor and the strength of the battery. He mentions that needles of brass and other materials were unaffected by the "electric conflict," as he calls the current. He concludes that:

> It is sufficiently evident from the preceding facts that the electric conflict is not confined to the conductor but [is] dispersed pretty widely in the circumjacent space. From the preceding facts we may likewise collect that this conflict performs circles. . . . This I think will contribute very much to illustrate the phenomena to which the appellation of polarization of light has been given.

Immediately afterwards Oersted published another paper which appeared in the July issue of Schweigger's *Journal für Chemie und Physik* and, in English translation, in Thomson's *Annals of Philosophy*. In this paper he shows that "the magnetic effects do not seem to depend upon the intensity of the electricity but solely on its quantity"; hence, a greater effect is produced by a single large cell than by a large battery of small cells. He also shows that a suspended circuit behaves like a magnet.

On the basis of notes found after Oersted's death, Doctor Kirstine Meyer has succeeded in reconstructing in considerable detail the series of experiments which he carried out in July, 1820. Her findings corroborate Oersted's own account.

The importance of Oersted's discovery was immediately recognized. Ampère wrote: "M. Oersted . . . has forever attached his name to a new epoch." Schweigger expressed the same opinion by beginning a new series of his journal. Faraday wrote of Oersted in 1821,

> . . . his constancy in the pursuit of his subject, both by reasoning and experiment, was well awarded in the winter of 1819 by the discovery of a fact of which not a single person besides himself had the slightest suspicion, but which, when once known, instantly drew the attention of all those who were at all able to appreciate its importance and value.

On a later occasion, he said of the discovery, "It burst open the gate for a domain in science, dark until then, and filled it with a flood of light."

In view of these clear statements of appreciation, it is strange that the stories should have developed that Oersted's discovery was purely accidental and incomplete, that the deflection of the needle was first observed by a janitor, that the discovery was not made by Oersted at all but by Schweigger, and so on. Doctor Meyer has shown that the chief errors, although elaborated by later German writers, originated in an article by the editor of *Annalen der Physik*, Gilbert, who had been unable to understand fully Oersted's Latin paper.

The rapidity with which new discoveries followed Oersted's is well known. Before the end of the year, Ampère had discovered the mutual action of currents, and Arago had constructed the first electromagnet. In 1821 Schweigger invented the "multiplier" or galvanometer and, with its help, Seebeck discovered thermoelectricity. This phenomenon made possible the use of constant electromotive forces and thus led to Ohm's discovery in 1824. An essential part of these advances was the clarification and quantitative definition of such concepts as current, potential difference and electromotive force.

It is symbolic of the great practical importance of Oersted's discovery that the headquarters of the Copenhagen Telephone Company now covers the very spot where he discovered electromagnetism.

Travel and Further Scientific Work

In 1822 Oersted set out on a trip to Germany, France and England, which lasted for nearly a year. Wherever he went, he was honored for his great discovery, for which he had already been awarded the Copley medal by the Royal Society of London and the gold medal of the French Academy. It is again interesting to note the change in his evaluation of the German and the French scientists. He writes:

> In poetry and philosophy I have not noticed that any new shining light has arisen in Germany in recent years. Nor does experimental science fare very well. Berlin has its excellent men in this branch of learning: Seebeck, Erman, Mitscherlich, Heinrich Rose, but from Berlin to Munich, on a journey of about 360 miles during which I have passed through three university towns, I have not found one fairly reliable chemist or experimental physicist. . . . But I found much that was instructive with Fraunhofer at Munich, so that I was able to occupy myself with benefit there for about a fortnight.

From Paris he writes:

> . . . the acquaintances I have made grow every day more cordial and intimate; the benefit I can derive scientifically is thus all the greater. Chevreul, Biot, Fresnel and Pouillet are the men I meet particularly often. . . . Comprehensive science and not only skill in a single branch is now their watchword. . . . If in Germany I am often tempted to protest against the Philosophy of Nature when I see how it is misapplied, in France I feel so much the more called upon to defend it, or rather I feel a fundamental difference in scientific thought which I should not have imagined to be so great if I had not so often felt its vital presence. Still, I am far from falling out with the French on account of this dissimilarity. I now know better than before to appreciate their merit and am therefore on better terms with them.

He had long discussions with Ampère but remained skeptical about the value of the latter's theory. Shortly after his arrival in Paris he gave a report of Seebeck's discovery and with Fourier, as well as alone, made experiments on the new phenomenon for which he proposed the name *thermoelectricity*. With Arago, Oersted discussed the possible connection between light and electromagnetism. In London, Oersted associated especially with Davy, Herschel and Faraday. He also met Wheatstone, who was then a young instrument maker. Oersted performed a number of experiments together with Wheatstone and introduced him to the English scientists.

The most important researches made by Oersted after his discovery of electromagnetism are undoubtedly his preparation of aluminum chloride and metallic aluminum, in 1825, and his extensive series of measurements of the compressibilities of liquids and gases. Since Oersted did not find time to describe his preparation of aluminum in complete form, his name usually is not associated with this achievement. However, a posthumous study of his notes has shown that his claim was well founded. The stimulation to his researches on compressibility came apparently from writing a textbook. These investigations, published in some 20 papers between 1817 and 1845, reveal him as a competent designer of apparatus and a careful and critical experi-

menter. His piezometer and the methods of measurements which he developed were of basic importance for the work of Despretz, Dulong and Arago. The great difficulty which Oersted and his contemporaries had in determining the correction required because of the compression of the glass vessel containing the liquid being studied is very instructive; it might well give present-day physics teachers food for thought.

Oersted's mind was very fertile in ideas, and his papers are full of statements which show that he was on the track of important discoveries. For example, he early surmised that the tangent of the angle of galvanometer deflection rather than the deflection itself should be taken as a measure of the current; he all but stated Ohm's law before it was announced by Ohm; he developed ideas of electric and magnetic fields, and anticipated in a vague way the electromagnetic theory of light. In all too many cases he did not carry his ideas to fruition. This was due in part to his reluctance or inability to give his ideas mathematical form, but it was also caused by the enormous range of his interests. However, while this great diversity of interests hindered him at times in imposing upon himself that limitation which is required for the complete solution of a scientific problem, it was an essential factor in his greatness as a teacher.

As Oersted became absorbed in the new educational enterprises described in the following pages, he naturally found less and less time for research. Yet he continued to experiment until the end of his life. His last experimental research, completed some two years before his death, dealt with diamagnetism and contained the important result that dia- and paramagnetic rods align themselves differently in a nonhomogeneous magnetic field.

In connection with Oersted's scientific work, it should be mentioned that he served as secretary of the Royal Danish Academy of Sciences and Letters for 36 years. His election to this post was followed by a period of reform of the Academy of Sciences and of great scientific advances in Denmark. The work took a considerable part of his time and energy. Thus, the annual *Proceedings*, containing abstracts of all the papers read at the weekly meetings, were written entirely by Oersted for 27 years. Oersted himself read 66 papers before the Academy, in addition to a large number of brief contributions. As secretary of the Academy of Sciences, he was instrumental in establishing the Meteorological Institute and the Magnetic Observatory at Copenhagen.

The Founding of the Society for the Diffusion of Physical Science

On his return trip from England, in 1823, Oersted conceived a plan for spreading the knowledge of physical science to a larger part of the population, and within a year he had founded the Society for the Diffusion of Physical Science in Denmark, with a membership of 200. In the printed invitation to join this society he emphasizes the importance that a more widespread knowledge of physics would have for the various crafts and industries, and thus for the economic welfare of the state; but he also points out that "the knowledge of the laws of nature form an essential part of man's whole range of knowledge and hence of his culture. As little as we are accustomed to admit this, it is nevertheless true."

The first activity of the Society was the holding of public lectures in Copenhagen by Oersted and two of his colleagues. Each gave two lectures a week, and the arrangement was such that the major parts of physics and chemistry and their applications were treated in a cycle of two winters. The attendance at Oersted's lectures was around 200. At the same time Oersted began to train several young men in the art of giving popular lectures with demonstrations. In order to get a practice school, Oersted offered to furnish a teacher in physics and chemistry to one of the secondary schools in Copenhagen; and the offer was accepted, although without enthusiasm. After half a year the first lecturer, equipped with a collection of instruments, was sent to Aarhus, the largest city in Jutland. He not only gave popular demonstration lectures but also acted as a technical consultant in much the same way as American county agricultural agents. In addition, he sent the Society reports on the condition of the industries in the province. Shortly afterwards three lecturers were sent to other towns. Since artisans worked long hours in those days, Sunday schools were established for them in several towns. In some cases the lecturer managed to get physics introduced in the local high school

with himself as unpaid teacher. This method of sending lecturers on physics to the provincial towns was continued for a number of years, although it did not work without difficulties, the chief one being that of securing qualified lecturers.

The Society for the Diffusion of Physical Science did much to encourage the introduction of physics into the schools, especially by lending or donating instruments to schools that were willing to adopt physics as a subject. The outcome was that, in 1845, physics became recognized as a regular part of the curriculum of the secondary schools. After the establishment of the engineering college in 1829, the number of popular lectures in Copenhagen was reduced. However, various new activities were taken up, such as the demonstrations of machines, which began in 1837. During the month of April, 1838, the attendance at these exhibitions was 2185. Printed descriptions and brief oral explanations of the steam engine, "the electromagnetic telegraph," "the electromagnetic motion machine," etc., were given; and the devices were shown in operation. Oersted gave much time and thought to the Society for the Diffusion of Physical Science; and the Society, which is still very active, deserves much credit for the high place that physics and chemistry hold in the interests of the Danish people. Since 1902 it has published the journal, *Fysisk Tidsskrift*, which serves a purpose similar to that of *The American Physics Teacher*. Since 1908, the Society has awarded a gold medal, the Oersted medal, accompanied by a cash prize.

Pioneering in Engineering Education

Although most interested in pure science, Oersted often stressed the benefits which would result from a greater application of physics to practical problems, and he early formed plans for an institution of the type now known as an engineering college. In 1827 one of the officers of the Society for the Diffusion of Physical Science sent plans to the government for the establishment of a trade school similar to a German "Gewerbschule." The proposal was turned over to a committee with Oersted as chairman. It reported that, while such a school might be useful, there was a greater need for an institution on a higher level, for "only a rather high degree of thoroughness can lead to a great and sure application of the natural sciences, and this higher insight is not reached without considerable preparation and prolonged study." Oersted, therefore, proposed that a "polytechnic institute" be formed. He worked out detailed plans whereby it was possible, by a moderate addition to the teaching staff and laboratories already available at the University, to establish such a college without great expense. The entrance requirements, he proposed, should be similar to those of the University. While mathematics, physics and chemistry were to be the chief subjects, he held that:

> . . . the teaching at the Polytechnic Institute must always strive to give the students not only the required knowledge but also such a practice in its application that this knowledge is not a dead treasure when they enter practical life. . . . I believe that no one acquires mathematical ability unless he trains himself in the solution of problems and in applying mathematics everywhere. . . . These lectures [in physics] must be accompanied by experimental exercises conducted in such a way that the students acquire competence in all types of physical experiments. . . . In order to bring about a more perfect cooperation between all the teachers, it is important that each teacher should know what doctrines the others teach; not in order to prevent differences of opinion which stimulate rather than harm when teachers have the requisite wisdom, nor to prevent that repetition of the same truths in different lectures which is inevitable in so related subjects, but in order to enable the teachers to have the proper regard to each other and to correct each other's knowledge in a friendly way. . . . The lectures should be based on printed textbooks. However, these need not be Danish but might be German or French.

Oersted insisted that the teachers should have the same status as University professors.

Oersted's proposal was accepted, and the new institution began its work in the fall of 1829 with Oersted as President and Professor of Physics. In addition, the original faculty consisted of a Professor of Mathematics, two Professors of Chemistry, a Professor of Applied Mechanics, and several teachers of lower rank. At the dedication ceremony Oersted delivered an address "On the Cultural Effects of the Application of the Natural Sciences." The number of engineering students was 22, but several of the lectures were attended also by University students. The course was

originally planned to take two years, but soon it was found necessary to increase the time of study.

The building up of the engineering college, then an entirely new type of institution, at a time when the economic conditions in Denmark were very bad was a task that taxed all of Oersted's ability and strength. But he entered upon it with enthusiasm and devotion. He expected a similar devotion from the faculty. In judging the value of a teacher, he would put teaching ability above scientific attainments, a policy for which he was sometimes criticized. He believed in teamwork on the part of the faculty and insisted, for example, that the professors of mathematics have a good knowledge of the subjects to which their students had to apply mathematics. He took a great personal interest in the students and in the apprentices in the shops.

For a number of years, the budget was very inadequate, and the salaries were low. "I have assumed," he said once in connection with the salary problem, "that we all carry this burden because we saw that the Polytechnic Institute would at present be discontinued if we would demand a salary corresponding to our labors." The difficulty of finding laboratory space for the increasing number of students and for research continued for many years. Shortly before his death, his plans for a great expansion of the Polytechnic Institute and for a substantial raise in the salaries were approved by the government; but he did not live to see them carried out.

Another problem which demanded Oersted's attention for many years was how to place the graduates in suitable positions. He had expected that the industries would be anxious to employ such well-trained men but had failed to reckon with the opposition of the guilds to their new competitors. He took up the fight with the guilds with his usual energy, and with considerable success, although the final victory came only in 1849, when a political upheaval gave Denmark a free constitution. Oersted also had to fight for the academic rights of the Polytechnic graduates. After some years they obtained the same status as University graduates, permitting them to hold fellowships and, on certain conditions, to dispute for the doctor's degree.

As the prestige of the Polytechnic Institute grew, the government referred more and more technical problems to it. Oersted himself wrote many important reports which bear witness of the broad understanding and clear vision that characterized his other activities. For example, when a foreign engineer applied for a monopoly on an improved telegraph, Oersted advised "that the construction of electric telegraphs either be undertaken by the government or at least be made a large public enterprise."

The Polytechnic Institute, now called the Royal Technical College, continues to enjoy a high reputation among European engineering schools. Besides the Physical Instrument Collection, it now has an Oersted Museum in which Oersted's instruments, including the famous compass needle, and many of his private possessions may be seen.

Poetic and Philosophic Writings

As previously mentioned, Oersted's first scholarly work was a paper on esthetics, and throughout his life he cultivated poetry and the fine arts. "I philosophize, experiment and write poetry," he once wrote in a letter. In 1836 he published a large poem, *The Airship*, in which he attempted to describe the rich and peaceful life that may be attained through the proper cultivation and application of the natural sciences. He sent a copy to the Swedish chemist, Berzelius, asking him to give it to his wife, and wrote in the accompanying letter: "I know that you do not like that one should thus scatter his strength in several fields; but that much I dare say in my defense that it could not be written except by a physicist." Berzelius replied: "You were, like Davy, born a poet, and your poetic bent has exerted its right in your old age. It is now thirty years since our first acquaintance and I remember, as if it were yesterday, how you then with delightful rapture read to me several of the shorter poetical works of Goethe." In the preface to *The Airship* Oersted wrote: "Amongst other things the sciences would seem able to a great extent to act as a guide to us in the investigation of the nature of the beautiful," an idea which he elaborated in a series of papers on "The Natural Philosophy of the Beautiful."

As Oersted grew old, he turned again to philosophy. However, his long scientific life had given him a sense for reality and a tempered judgment, which he had not always possessed in his youth. Having lived a harmonious and happy

life, he never lost his intellectual enthusiasm and optimism or his strong faith in the value of physical science. "It belongs to my plans as a physicist," he wrote in 1836, "to make it evident in every way that the natural sciences should form an essential part of general culture." Some years later he wrote about his work in the decade following the establishment of the Polytechnic Institute:

> My scientific activity in this period is especially marked by an effort to work for my language and my people through popular papers. I have aimed here both at the better educated and the less educated classes. If I am not mistaken, there are certain influences upon human society which ought to issue from the scientists proper, and it is still my opinion that especially the type of thought which is developed by the cultivation of natural science should be extended to a wider circle. Without doubt, the greatest fault of our present culture is an inclination to settle the most important matters according to certain abstract principles without entering into the true relations of these principles to reality. The extremes to which one thereby is misled, be they political, religious, or metaphysical, are all based upon a lack of sense for the truth and reason which lie in the real. That visionary inanity Natural Science is particularly fitted to counteract. I have attempted to apply the scientific spirit in the treatment of religious, esthetic and philosophic topics. That I am far from having produced the effect which I desired is very clear to me; but that I hereby have sown some seeds among the young people who usually flock to my lectures and conversations I dare believe, and I venture to hope for fruits in the future. . . .

His respect for reality is also revealed in the words:

> Should we not feel ashamed in our innermost soul if we caught ourselves in desiring another truth than the real? . . . Let us honor truth! With it the good is inseparably connected. The full truth carries itself its consolation with it.

Statue of Oersted in the Oersted Park at Copenhagen.

Oersted's conception of the laws of nature is indicated by the following statement:

> The train of ideas through which empirical science comes to realize that the laws of nature are laws of reason is not based on any consideration of the wisdom of these laws . . . but depends upon our seeing that which reason perceives confirmed in nature. It is true that we often come to recognize the agreement of the laws of nature with reason only after finding these laws in experience; but often thought runs ahead of experience, and we find that which is thought verified by nature. Hence, we may say in numerous cases: what reason promises, nature keeps.

The idea of unity is again prominent in Oersted's later philosophic writings:

> The laws of nature in the bodily world are laws of reason, the revelation of one reasonable will; if thus we figure to ourselves the whole bodily world as the continual work of eternal reason, we cannot abide by the consideration of this but are carried on to perceive in our thinking also the same laws of the universe. In other words, spirit and nature are one, viewed under two different aspects. Thus we cease to wonder at their harmony.

About two years before his death Oersted completed a large work, *The Spirit in Nature,* which reached several editions and was translated into a number of languages. In this book he attempts to show that religion, art and philosophy must all be based upon that conception of an order in nature to which we are led by natural science. "The world drawn by the poet, with all its freshness and daring, must after all obey the same laws that our spiritual eye discovers in the real world," he once wrote. Scientific work was to Oersted a sort of religious worship. "God's will can never deviate from the laws of nature for the simple reason that the laws of nature are God's will." He had little use

for the dogmas of the Church and on occasions engaged in public controversy with a bishop. He held that Christ has taught us great truths, but has given us no system.

In order to reach a greater part of the population, he often expressed his thoughts in the form of aphorisms or maxims, such as these:

> It is a common spiritual disease to like a new delusion better than an old truth.
>
> When a philosopher scorns Nature because it puts his concepts to shame, he acts like a child who spanks the object that hurt it.
>
> Logic is a dangerous weapon in the hands of passion.
>
> Be stricter to yourself than to others; your egotism is sure to make up for this lack of fairness.

Personality

Oersted possessed a radiant and harmonious personality. He was an optimist by nature and continued to have throughout his life a strong, almost naïve, faith in science and in his fellowmen. He was happy in his work. He was happily married and was a thoughtful husband and father. A friend once came to visit him in his study and found him busy clearing some things from a table. "My wife," Oersted explained, "is going to send my little boy in here, and I put the things away before he comes because I don't like to forbid him to touch them." His home was an intellectual center in Copenhagen and a gathering place for writers, philosophers and scientists. He had many friends whom he was always ready to help by word and deed. "There is nothing in him which one needs conceal or put into a better light before showing it to the world," wrote C. Hauch in 1852, "hence one may well say of him that he was not only a great scientist and a rare thinker but also that he was a great and rare man."

To Hans Christian Andersen, as well as to Zeise and his other students, Oersted was a fatherly and faithful friend. He was the first to appreciate the merits of Andersen's fairy tales and was always ready to console and encourage the poet. Andersen wrote:

> I always returned so clear in thought and rich in mind from the lovable and glorious Oersted; and in the darkest hours of misjudgment and despair it was he who supported me and promised me a better time. . . . One day when I had left him, sick in my soul from the injustice and hardness shown me by others, he could not rest before he, the older man, had looked me up at my house, late at night too, and there once more expressed his sympathy and consolation. It affected me so deeply that I forgot all my sorrow and pain and wept my fill in gratitude and bliss over his infinite goodness; I won again strength and courage to write and work. . . . his wealth of knowledge, experience, and genius, his charming naiveté, something innocent, unconscious as in a child, a rare character with the stamp of divinity were here revealed. . . . He was so mild and good. A child at heart and yet a deep philosopher.

Oersted worked happily to the very end. In March, 1851, he died, after less than a week's illness. He was mourned by his family, by his friends, and by the Danish people.

The Oersted medal of the American Association of Physics Teachers. In 1937 it was awarded to the late Professor Edwin H. Hall and in 1938, to Professor A. Wilmer Duff. A blank of the medal has been sent to Denmark for deposit in a collection commemorating Oersted's work. Professor Frederic Palmer, Jr. suggested the motif appearing on one face of the medal; namely, Oersted, scientist and teacher, discovering electromagnetism in the presence of his assembled pupils. The scene depicted is based on information obtained for the Committee on Awards by Professor J. Rud Nielsen, formerly of Copenhagen, and Professor F. K. Richtmyer, and is believed to be highly authentic. The design of the medal was carried out by the firm of Dieges and Clust.

Concepts and Definitions of Electromotive Force

L. M. ALEXANDER
Department of Physics, University of Cincinnati, Cincinnati, Ohio

CONCEPTS are neither true nor false from the empiric point of view; the essential problem in connection with them is one of meaning. It is therefore extremely important that the meaning of a concept in physics be as precise, clear and intelligible as possible. The concept of *electromotive force* is presented in many elementary textbooks in such a way as to be quite unintelligible to a beginner; in addition, different textbooks may give distinctly different meanings for the term. Since a reasonable understanding of electricity as a whole depends so much upon a clear conception of the idea of potential, this is an unfortunate and serious situation.

An examination of 24 physics textbooks of college grade—2 advanced, 3 intermediate and 19 elementary—shows that there is a wide variety in the presentation of this concept, with at least three distinctly different statements as to its meaning. In the condensed outline that follows, these various definitions of electromotive force are grouped according to the three different meanings.

Texts that seem to imply that any difference of potential whatever may be designated as an electromotive force. (1) Electromotive force is the difference of potential between any two points. [Four texts.]

Texts that seem to imply that electromotive force is a special type of potential difference. (1) Emf is the difference of potential that a galvanic cell or other generator of electricity is able to maintain between its terminals when these terminals are not connected by a wire. (Sometimes defined as the total electrical "pressure" that a generator is capable of exerting.) [Nine texts.]

(2) Strictly speaking, an emf is set up by a battery, or dynamo, while a difference of potential exists between any two points on a conductor in which a current exists. [One text.]

(3) The emf of a circuit is numerically equal to the work done against electrical forces when unit quantity of electricity is carried around the complete circuit. [One text.]

(4) The rate at which energy is expended to maintain unit current measures the emf. [Two texts.]

(5) The rise of potential at the surface of a plate is the measure of the emf applied to the circuit at this surface, and the sum total of all the rises is called the emf applied to the circuit. [One text.]

(6) Emf is the agency causing the flow of electricity. [Four texts.]

Texts that seem to imply that emf is a mechanical force. (1) Electromotive force can be defined as that force which moves or tends to move electricity. [Two texts.]

The term, electromotive force, itself, is unfortunate. Almost all texts explain that electromotive force is not a force. This is confusing to a beginner, and he questions why it should be called by this name if it is not a force. A. W. Duff[1] has suggested the use of the word *electromotance* instead of electromotive force. The adoption of this valuable suggestion would eliminate one source of confusion in connection with the concept.

The term *potential difference* is employed in different ways in connection with circuits. Some authors use it to designate a general potential difference, while others use it to designate only the special type of potential difference across a pure resistance carrying a current, usually called a *potential drop*. It should not be difficult to standardize the meaning of the term *potential difference.*

The sense of progression from lower to higher potentials, to be named *sense of increasing potential*, and its indication by an arrow, not to be considered a vectorial direction, is an important and useful idea that is usually omitted from textbooks. Potential and the total current are both scalar quantities; and while no one hesitates to use an arrow on a wire in a diagram to indicate the "direction"—or better, the sense of the current—there is a curious reluctance to the use of a similar arrow in connection with difference of potential in general, or emf in particular, yet it is impossible to solve a Kirchhoff's law problem without using some idea equivalent to associating an arrow with an emf. This arrow denotes the sense in which the emf "acts" in the circuit, or what is the same thing, the sense of the emf. Since the positive sign at one terminal of a source of emf denotes that this terminal is at the higher potential, insofar as

[1] Am. Phys. Teacher **6**, 219 (1938).

the emf is concerned, the sense of the emf is denoted by an arrow (not to be considered as a vector) from the negative to the positive terminal of the emf device. The usual + and − convention for emf is ambiguous and misleading in some cases. It is believed that use of the expressions *sense of increasing potential* and *sense of the emf* would obviate many of the difficulties encountered by beginners.

Many texts do not mention counter emf (cemf) except in connection with an electric motor.[2] Yet this concept is very important in connection with the energy interchanges in a circuit, and also with the definition of emf itself.

It is essential that emf, potential drop and general potential difference be denoted by different symbols, and that the notation be consistent throughout. Many texts fail in these respects, with the result that the reader is confused. Another source of confusion is the lack of a standardized nomenclature. The following names for various potential differences are in fairly common use in textbooks:

> Potential difference, potential drop, emf, counter emf, back emf, potential, voltage, lost volts, useful volts, terminal volts, whole internal emf, external emf, electrical pressure, total electrical pressure, maximum potential difference, fall of potential, *IR*-drop, voltage drop, P.D., etc.

All the points discussed with this multiplicity of nomenclature may be treated accurately and completely with the use only of the first four names in this list (or their equivalents), provided they are defined precisely and intelligibly. In most other branches of physics the nomenclature is fairly well standardized, and there is no reason why this cannot be done in electricity. For the purposes of this article, emf and cemf will be denoted by the symbol e; potential drop by E; general difference of potential between any two points a and b by $\mathcal{E}_{ab}$ or, where the points are obvious, by $\mathcal{E}$. The relation between these potential differences for any points a and b is

$$\mathcal{E}_{ab}=\Sigma e-\Sigma E$$

or, more specifically,[3]

$$\mathcal{E}_{ab}=\Sigma e-\Sigma RI. \tag{1}$$

The numerical signs in Σe and in ΣRI are determined precisely as in Kirchhoff's second law, since the latter is merely a special case of Eq. (1). Although the terms *potential drop*, *emf*, and *counter emf*, if properly defined, indicate by their names the sense to be associated with them, this is not true of the term *difference of potential;* hence the necessity for having this information supplied in some other manner. For this purpose, we let $\mathcal{E}_{ab}$ denote the general potential difference obtained by starting at the point a and proceeding over any path of the circuit to the point b, so that if the right-hand member of Eq. (1) gives an answer with a positive sign, the sense of increasing potential is from a to b, and if negative, from b to a. This convention of signs is equivalent to the identity $\mathcal{E}_{ab}\equiv\phi_b-\phi_a$.

Ten of the texts previously mentioned attempt to use a hydraulic analogy to explain emf, and they do so by associating emf with pressure. Seven of the texts use "electrical pressure" as synonymous with electric potential, or emf. This is unfortunate, and certainly misleading to a beginner. The student already knows that pressure is "force per unit area;" and it is difficult for him to see, after reading the analogy, that potential is "work per unit charge." It seems that use of the words "pressure" and "force" in connection with electric potential is a sure source of confusion.

Many definitions of emf given in textbooks are not operational in any sense of the word. If emf is defined in terms of energy interchanges, however, the definition is entirely operational. From this viewpoint a satisfactory and intelligible definition of emf must take into account the energy interchanges taking place. If this be correct, counter emf must also be defined explicitly, as here the energy interchanges are the reverse of those for emf. The fall of potential through a resistance reverses when the current reverses, so the energy interchange here is irreversible—that is, independent of the sense of the current—a sufficient reason for giving a special name, *potential drop*, to this potential difference.

[2] Most texts do discuss the counter emf of a motor, meaning thereby that the sense of the emf is counter to the current. On the other hand, the counter emf of self-induction means that the sense of the emf is always counter to the time-rate of change of current. The term *counter* used in these two ways is somewhat misleading.

[3] L. M. Alexander, Am. Phys. Teacher **6**, 68 (1938).

A Proposed Treatment of Potential

An attempt[4] will be made to formulate a satisfactory treatment of potential that is suitable for elementary college courses. No claim is made that this is the best possible treatment, but perhaps it will promote discussion that will eventually evolve the best treatment of this important subject.

It is usual to define difference of potential in electrostatics as "work per unit charge," and to accompany this definition with a discussion of what it means. The idea of the "sense of increasing potential" should be included in the definition. It would be well at this stage to point out to the student that the definition is general, and will be adhered to throughout the remainder of the work in electricity. This general concept could be denoted by the symbol $\mathcal{E}$, and named *difference of potential* or *potential difference*.

After electric current is defined, it is then possible to derive the general expression for power in a portion of a direct-current circuit in the form $P \sim \mathcal{E}I$. Although we are now in a position to compute numerically the net power interchange, we do not know in detail what these power interchanges are. We are able to make one general statement regarding power interchanges, however: Assume that a current I exists between two points of difference of potential $\mathcal{E}$; then, if the sense of increasing potential is the same as the sense of the current, the net power interchange, $P=\mathcal{E}I$, expresses the time-rate of transformation of energy from some other form to electric,[5] and conversely.

To break down the net power interchange into its component parts, it is necessary to subdivide the general difference of potential into: (1) that type of potential difference in which the power interchange does not depend upon the sense of the current (potential drop); (2) that type in which the power interchange reverses when the current reverses. We shall further subdivide the second type into two sub-types (emf and cemf), in order to distinguish clearly between the two types of possible power interchanges.

Definition of potential drop, E

One irreversible power interchange—that is, power interchange independent of the sense of the current—occurs when there is a current in a pure resistance. Here the energy interchange is from electrical energy to heat, *no matter which way the charges flow. Potential drop*, symbol E, is now defined to be the potential difference between the end points of a pure resistance (of constant temperature, homogeneous, etc.) having a current in it.[6] Thus, the power, $P=EI$ (d.c.), denotes a power interchange *only* from electric to heat power. If Ohm's law be interpreted[3] as the relation between this potential difference, the resistance, and the current, we have $E=RI$ as Ohm's law and $P=EI=I^2R$ as the power interchange for this case in a direct-current circuit.[7]

Almost all other differences of potential in electricity involve reversible power interchanges, which depend upon the sense of the current. We shall name any such potential difference either emf or cemf, depending upon its relation to the current.

Definition of emf, e

An emf,[8] symbol e, exists in every current-carrying, electric device in which there is any energy conversion from some other form to electric energy. Because of this energy transfer, the device is a *source* of electric energy; and at least one such source must be present, at ordinary temperatures, if there is to be a current in the circuit. The emf may be evaluated by means of the equation $e=P/I$ (d.c.), where e is the emf, I the current, and P the time-rate of conversion from some other form of energy to electric. In every such case the sense of the increasing potential involved in this transformation of energy is found to have the same sense

[4] Somewhat similar discussions of potential will be found in the following texts: Hirst, *Electricity and Magnetism* (Prentice-Hall, 1937); Gilbert, *Electricity and Magnetism* (Macmillan, 1932); Randall, Williams and Colby, *General College Physics* (Harpers, 1937); Gilbert and Murch, *Elementary College Physics* (Harcourt Brace, 1937); Starling, *Electricity and Magnetism* (Longmans, Green, 1929).

[5] Here, and following, "electric energy" means kinetic electric energy.

[6] When a current-carrying resistance is associated intimately with some other type of potential difference, as in a cell with an internal resistance, reference may still be made to the "potential drop in the cell," computed as $E=RI$; but it must be stressed that it is not, in general, equal to the potential difference across the cell.

[7] Note that the expression $\mathcal{E}I=I^2R$ is not necessarily valid. This shows the need for an adequate and consistent notation.

[8] Or *electromotance* (reference 1), in which case the abbreviation might well be "emt."

as the current, and it is defined as the *sense of the emf*. The power interchange, $P=\underset{\rightarrow\rightarrow}{eI}$ (d.c.), expresses[9] the time-rate of conversion of energy from some other form to electric, as in the following examples:

Continuous current sources	*Energy interchange from*
Discharging cell	chemical
D.c. generator	mechanical
Photovoltaic cell	radiation
Emf junction of thermocouple	heat
Variable current sources	
Discharging condenser	potential electric
Self- or mutual-induction	magnetic

Definition of *counter emf*, *e*

A *counter emf* (cemf),[10] symbol e, is said to exist in every current-carrying, electric device in which there is any energy conversion from electric to some other form of energy, provided further that this energy interchange is reversible. This counter emf may be evaluated by means of the equation $e=P'/I$ (d.c.), where e is the counter emf, I the current, and P' is the time-rate of (reversible) conversion of electrical to some other form of energy. In every such case it will be found that the sense of increasing potential involved in this transformation of energy is counter to the sense of the current, and therefore it is defined as the *sense of the cemf*. The power interchange, $P'=\underset{\rightarrow\leftarrow}{eI}$ (d.c.), expresses the time-rate of (reversible) transformation of energy from electric to some other form, as in the following examples:

Continuous current sources	*Energy interchange to*
Charging cell	chemical
Motor	mechanical
Cemf junction of thermocouple	heat
Variable current sources	
Charging condenser	potential electric
Self- or mutual-induction	magnetic

As to the practical conditions for the measurement of emf or cemf, it is merely necessary to apply Eq. (1) between two points a and b on either side of an emf device, whence

$$\mathcal{E}_{ab}=\pm e-(\pm RI),$$

where e is the emf (or cemf), R the resistance, $\mathcal{E}_{ab}$ the potential difference between the points a and b, and I the current in the device. We see that there are two methods of measuring the emf. We may measure the potential difference between the terminals, adding or subtracting the internal drop (depending upon the sense of the current), or we may measure the potential difference between the terminals when no current is present, for this potential difference is numerically equal to the emf *under these conditions*. If the emf is a function of the current, as in the case of a generator under load, the open-circuit potential does not give the value of the emf under load. In the case of the emf of self-induction, it is not possible to measure the open-circuit potential.

It is to be noted that it is impossible to specify a potential drop, emf, or cemf unless the current (actual or implied) is taken into account, since a potential drop does not exist in the absence of a current, and it is impossible to distinguish between an emf and a cemf until the sense of the current is known. It is not feasible to use different symbols to denote emf and cemf, since, in a general circuit problem, it is not known which potential differences are emf and which are cemf until the correct senses of the currents are found in solving the problem.

In the foregoing treatment of potential, an attempt has been made to: (a) avoid the use of the ideas of force or pressure in connection with emf; (b) point out that potential drop, emf, and cemf are potential differences, in fact, merely special cases of the general definition of potential difference; (c) describe the power interchanges

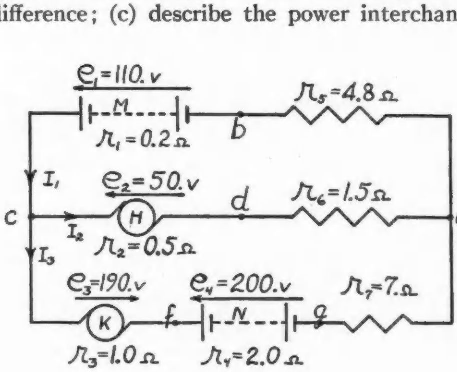


FIG. 1. Illustrative problems.

[9] Each arrow represents a sense, not a vectorial direction.
[10] Or *counter electromotance* (cemt).

taking place, and the method of computing them; (d) use a notation that distinguishes clearly between a general potential difference, a potential drop, and an emf (or cemf); and (e) give enough properties of potential drop, emf, and cemf so that the student will have a clear conception of their meanings, thus enabling him to solve more complex problems than are found in most elementary texts.

The following direct-current, complex circuit problems illustrate many of the points brought out in this article.

Problems

Referring to Fig. 1, where H and K are rotating devices:

1. Find the current in each branch.
2. Find the potential differences $\mathcal{E}_{ab}$, $\mathcal{E}_{cd}$, $\mathcal{E}_{gc}$, and $\mathcal{E}_{ac}$, the last to be computed for three different paths.
3. Analyze the energy interchanges in each part of the circuit.
4. Compute the net power in the line cfg, and compare this with the separate power computations for this part of the circuit obtained in Problem 3.
5. Identify the devices denoted by H and K.

Solutions

1. The ordinary methods of solution yield: $I_1=10$, $I_2=5$, $I_3=5$ amp.
2. The potential difference between any two points of a circuit may be computed from the equation $\mathcal{E}_{ab}=\Sigma e-\Sigma RI$.

Path	Potential difference	Sense of increasing pot.
shortest	$\mathcal{E}_{ab}=0-(10\times4.8)=-48$ v	b to a
shortest	$\mathcal{E}_{cd}=-50-(5\times.5)=-52.5$ v	d to c
shortest	$\mathcal{E}_{gc}=200-190-(-5\times3)=25$ v	g to c
upper	$\mathcal{E}_{ac}=110-(10\times5)=60$ v	a to c
middle	$\mathcal{E}_{ac}=50-(-5\times2)=60$ v	a to c
lower	$\mathcal{E}_{ac}=200-190-(-5\times10)=60$ v	a to c

The three computations for $\mathcal{E}_{ac}$ give the same answer, as they should, since the potential difference between two points of a circuit is independent of the path. This provides a numerical check on the original computations for the unknown currents.

3. The potential difference e_4 is a counter emf, therefore the equation $P=e_4I_3$ expresses the time-rate of conversion of electric energy into energy of some other form. Inspection shows that the other form of energy here is chemical; and $P_1=e_4I_3=200\times5=1000$ w, electric to chemical. In addition, a current exists in the internal resistance of this battery; and $P_2=I_3^2r_4=25\times2=50$ w, electric to heat. The potential difference e_3 is an emf, and the power P_3 $(=e_3I_3)$ expresses the time-rate of conversion of some other form of energy into electric energy. Inspection shows that the other form here is mechanical; and $P_3=e_3I_3=190\times5=950$ w, mechanical to electric, while $P_4=I_3^2r_3=25\times1=25$ w, electric to heat, etc. Upon adding all the power interchanges, it is found that electric energy is appearing and also disappearing at the rate of 2050 w.

4. From Problem 2, $\mathcal{E}_{cfg}$ is found to be a counter potential difference of 25 v. The net power interchange on the line cfg is $P_5=\mathcal{E}_{cg}I_3=25\times5=125$ w; and since $\mathcal{E}_{cfg}$ is a counter potential difference, the net transfer of energy is from electric to some other form. The answer to Problem 3 shows for this portion of the circuit a total transfer of power *to* electric of 950 w, and a total transfer *from* electric of 1075 w. The net transfer is $1075-950=125$ w from electric to some other form, thus checking the previous computation.

5. As soon as the correct current senses are obtained, it can be seen by inspection that K is a generator and H is a motor.

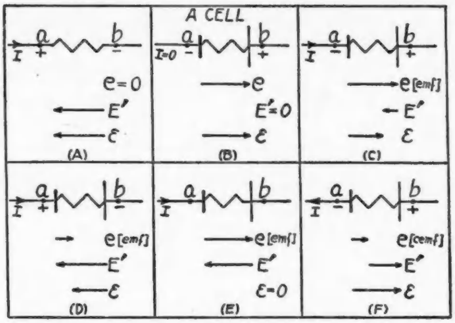


FIG. 2. Combinations of various potential differences.

The significance of the relation between general potential difference, emf, cemf, and potential drop, as expressed by Eq. (1), may be demonstrated clearly to the student by means of diagrams similar to those of Fig. 2. They show all the possible cases arising with a resistance only, an emf only, a resistance and a single emf, and a resistance and a single cemf. In accordance with universal custom, difference of potential across a resistance is defined here as a *fall* of potential, denoted by E, so that a *rise* of potential becomes $-E(=E'$, say), which must always be drawn counter to the current. All arrows in Fig. 2, therefore, denote rises of potential, and the lengths of the arrows denote the magnitudes of the various potential differences. The general difference of potential between the points a and b, as read by a potentiometer, is denoted by $\mathcal{E}$ and its polarity is indicated by the + and − signs, or by the sense of the arrow for $\mathcal{E}$. Since all arrows represent rises of potential, $\mathcal{E}$ is obtained by vector addition of e and E'.

The situation arising in Fig. 2*D* prompted the remark made earlier in this article—that the usual + and − convention for emf is ambiguous and misleading in some cases. This situation is by no means uncommon. Frequently some cell in a battery will develop an abnormally high resistance and, if the current is sufficiently large, will show a reversed polarity under load. This is sometimes diagnosed as a reversed emf, which is obviously not the case here. The use of + and − signs to indicate the polarity of the emf, and of other + and − signs to indicate the true polarity of the terminals, results in a contradiction in any arrangement similar to Fig. 2*D*. Also, + and − signs placed at the points *b* and *a* to indicate the polarity of the emf in any arrangement similar to Fig. 2*E* would be misleading, as the difference of potential $\mathcal{E}$ between these points is zero. These are some of the reasons for proposing the use of an arrow, rather than the usual + and − signs, to indicate the sense of the emf. In any case, if + and − signs are to be used at all, it should be made quite clear to which potential difference the polarity signs refer.

Free Charges, Polarization and Polarization Charges, Especially Those Produced When an Insulator Moves in a Magnetic Field

S. J. Barnett
University of California, Los Angeles, and California Institute of Technology, Pasadena, California

THIS paper is written with the hope that it will give the student who is already somewhat acquainted with the subject a better idea of free charges, polarization and polarization charges than can readily be obtained elsewhere. Only static fields are considered.

The first part is introductory to the second, and contains a brief elementary treatment—systematic but intentionally incomplete and more or less skeletal—of the subject of the polarization of insulators in an ordinary electric field (without regard to detailed molecular theory). This subject is for the most part well understood, but is usually not well treated even in books which are in many ways excellent. The second part extends and applies this treatment to very interesting and important cases in which polarization is produced in insulators, and free charges in conductors, by their motion in a magnetic field, especially the case of a circular cylinder of insulating material rotating about its axis in a uniform magnetic field with intensity parallel thereto. Most details of such a cylindrical polarization field have not been published before. The third part gives very brief descriptions of experiments in this latter field, which, although of great importance in electrical theory, seems to be known scarcely at all to most teachers and to most writers of textbooks on physics. The second part of the paper has not been written for the sake of the experiments in the third, which makes use of only a small part of the theory in the second. The third part, however, is intended to show how the theory of the second has been verified insofar as it relates to the theories of Lorentz and Einstein, now so fully confirmed in other ways.

2. In Fig. 1, *A* and *B* represent the two equal parallel plates of an electric condenser *in a vacuum*. The linear dimensions of the plates are supposed so great in comparison with their distance apart that edge effects are negligible, and the charges, of densities σ_f and $-\sigma_f$, are restricted to the opposing faces. These charges were produced by *conduction* from the terminals of a generator, or by *contact and separation*, and will be referred to as *free* charges.[1] The electric intensity between the two plates will be designated by E_f. If now a dielectric slab (of dielectric constant K) is introduced symmetrically between the insulated plates, the positive and negative electricities (of volume densities ρ and $-\rho$) of which it will be assumed to be composed, will be shifted relatively a minute distance δx, the positive electricity downward, thus creating *polarization* charges[2] with surface densities

[1] For a long time, and often still, referred to as *true* charges.

[2] For a long time, and often still, referred to as *apparent* or *fictitious* charges.

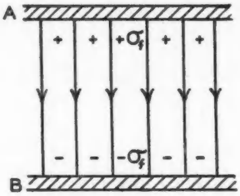


FIG. 1. Parallel-plate condenser in vacuum.

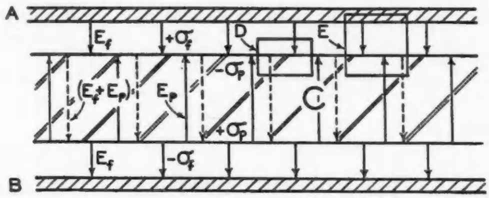


FIG. 2. Parallel plate condenser with material dielectric

$-\sigma_P=-\rho\delta x$ and $\sigma_P=\rho\delta x$ at the top and bottom of the slab. The positive and negative electricities within the body of the slab remain superposed so that the total volume density is zero within the slab. The polarization charges create a polarization field within the slab, whose intensity E_p is directed upward (negative). The resultant intensity E is directed downward (positive). The resultant intensity within the slab is $E_f+E_p\equiv E$, which is less than E_f since E_p is negative. The quantity $\sigma_P\equiv\rho\delta x$ is also clearly the electric moment per unit volume of the polarized dielectric. The surface densities σ_f and $-\sigma_f$ on the plates, and the intensity E_f between the plates and the slab, remain unaltered by its introduction.

3. Let us now consider an imaginary closed surface Σ of area S surrounding any number of conductors or insulators or both, charged in any way. As before, we assume that these bodies are built of positive and negative electricities, so that within Σ we have only the two kinds of electricity distributed in a vacuum. Let e_n denote the normal component (measured outward) of the electric intensity at any point P of the surface due to any point charge q within the surface. Then $\int e_n dS$, the integral of e_n over the surface, is equal to $4\pi q$, independently of the position of q within the surface. Thus, if we designate by E_n the normal component at P of the total electric intensity due to the sum Q of all the charges within Σ, we have, by the principle of superposition,

$$\int E_n dS=4\pi Q, \qquad (3\text{–}1)$$

which is the general integral form of *Gauss theorem*. This theorem in its differential form is thus

$$\operatorname{div} E=4\pi\rho, \qquad (3\text{–}2)$$

where ρ is the *total* volume density at the point at which the intensity is E.

4. Now consider a surface Σ of area S which surrounds or passes through polarized matter. Inasmuch as polarization simply *shifts* the opposite kinds of electricities, it is clear that if there is any *polarization* charge within Σ it is the polarization charge which enters *through* Σ. This is easily shown to be

$$Q=-\int P_n dS \qquad (4\text{–}1)$$

over the surface, where P_n is the outward normal component of the polarization P. The differential form of this law is

$$\rho_P=-\operatorname{div} P, \qquad (4\text{–}2)$$

where ρ_P is the volume density of polarization charge at a point where the polarization is P.

Inasmuch as the total charge Q within any surface is equal to the sum of the free charge Q_f and the polarization charge Q_P within the surface, we have, from Eqs. (3–1) and (4–1),

$$Q=(1/4\pi)\int E_n dS\equiv Q_f+Q_P=Q_f-\int P_n dS, \qquad (4\text{–}3)$$

and from (3–2) and (4–2),

$$\rho\equiv 1/4\pi \operatorname{div} E\equiv\rho_f+\rho_P=\rho_f-\operatorname{div} P. \qquad (4\text{–}4)$$

From (4–3) we obtain

$$4\pi Q_f=\int(E_n+4\pi P_n)dS, \qquad (4\text{–}5)$$

and from (4–4),

$$4\pi\rho_f=\operatorname{div}(E+4\pi P). \qquad (4\text{–}6)$$

If we define the vector sum of E and $4\pi P$ as the *electric displacement* D, so that

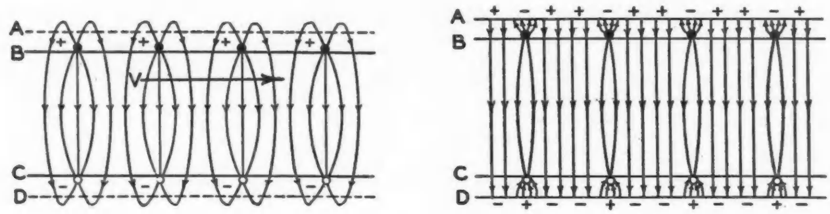
$$D=E+4\pi P, \qquad (4\text{–}7)$$

these equations become

$$4\pi Q_f=\int D_n dS \qquad (4\text{–}8)$$

and

$$4\pi\rho_f=\operatorname{div} D, \qquad (4\text{–}9)$$



(a) (b)

FIG. 3.

which are the integral and differential forms of Gauss' theorem for the *free* charge.

The foregoing equations are perfectly general,[3] and do not depend for their validity on the manner in which D and P are produced.

5. We shall first consider the case in which D and P are produced by the action of E (the field intensity due to *all* the electric charges), in which the dielectric is isotropic, so that E, D and P all have the same direction, and in which, furthermore, P is proportional to E (which is true in many cases) so that

$$P=\epsilon E, \tag{5–1}$$

where ϵ is a constant (the susceptibility). Then we have *both*

$$D=E+4\pi P \qquad (4\text{–}7)\ bis\ (5\text{–}2)$$

and

$$D=KE\equiv(1+4\pi\epsilon)E, \tag{5–3}$$

the last equation defining the *dielectric constant* K.

For the special case just considered, Eq. (4–8) becomes

$$4\pi Q_f=\int KE_n dS. \tag{5–4}$$

If the dielectric constant K is uniform all over those parts of the surface Σ where E_n is not zero[4] (as it will be where the surface passes through a conductor or through an insulator parallel to the lines of intensity), Eq. (5–4) becomes

$$4\pi Q_f=K\int E_n dS. \tag{5–5}$$

Eqs. (3–1) and (5–5) therefore give, for this case,

$$Q_f=KQ\equiv K(Q_f+Q\ ). \tag{5–6}$$

Thus we have

$$Q=Q_f/K \tag{5–7}$$

and

$$Q_P=Q_f(1-K)/K=Q(1-K), \tag{5–8}$$

which are often very useful.

For the same case we have likewise

$$\rho=\rho_f/K \tag{5–9}$$

and

$$\rho_P=\rho_f(1-K)/K=\rho(1-K). \tag{5–10}$$

6. If we apply Eqs. (5–3) and (5–4) to the closed surface D of Fig. 2, we see that

$$KE=E_f \quad \text{or} \quad E=E_f/K, \tag{6–1}$$

so that the potential difference between the plates will be reduced to the fraction $1/K$ of its value by substituting for the ether between the plates a slab of dielectric constant K. If we apply Eq. (5–8) to the surface E, we see that

$$\sigma_P=\sigma_f(1-K)/K. \tag{6–2}$$

7. In the examples just cited we have considered only very simple cases in which the polarization is due exclusively to a *field intensity* E. We shall now consider some less familiar but still more instructive cases, which require a knowledge of what precedes and in which the polarization is produced partly by an *intrinsic* intensity e, and only partly by the field intensity E. As the intrinsic intensity we shall take the motional electric intensity $e=[vB]$ acting on either a dielectric or a conductor moving through a magnetic field.

In Fig. 3(a) the dielectric slab BC, with constant K, moves to the right with velocity v through a uniform magnetic field whose induction B is directed into the paper parallel to the top and bottom of the slab and normal to the velocity v. Each of the electrical particles, with charge q, of which the slab is constituted will be acted upon by a force $q[vB]$. The force per unit

[3] That is, on the theory of Maxwell and Lorentz. On Hertz's theory certain modifications are necessary, as in Sec. 9 below, for example.

[4] The surface Σ may inclose any number of insulators with any dielectric constants, and any number of conductors.

charge, or motional intensity e, is thus $[vB]$. The positive electricity will be driven upward; the negative, downward. The slab is thus polarized, P being directed upward. A layer of positive electricity will accumulate on the upper surface of the slab; and a layer of negative electricity on the lower surface. The resulting electric field is shown *diagrammatically* in Fig. 3(a). Lines of electric intensity E proceed from the positive charges on the upper surface of BC to the negative charges on the lower surface. The dotted lines A and D, extremely close to B and C, indicate the positions of thin conducting plates to be introduced later.

We shall now proceed to find the polarization P within the dielectric, which is equal to the polarization surface density at the top of the slab, together with the electric displacement D and the field intensity E (all reckoned positive in the upward direction).

We are, at present, assuming the theory of Lorentz, according to which the intrinsic intensity e acts only on the *material* part of the dielectric, whose total dielectric constant is K, while the field intensity acts on the complete dielectric (including both ether and matter). Eq. (5–3) now no longer holds, but must be replaced by[5]

$$D=(K-1)e+KE. \tag{7–1}$$

Here 1 is the dielectric constant of the *ether*, $K-1$, that of the *matter alone*, which moves while the ether remains fixed. Eq. (4–7), namely,

$$D=E+4\pi P, \tag{7–2}$$

still holds.

In the first place, the mean (macroscopic) displacement D is equal to zero, as there is no mean (macroscopic) free surface density anywhere; that is, the mean *upward* displacement due to $[vB]$ is just balanced by the mean *downward* displacement due to E. For the value of E Eq. (7–1) thus gives

$$E=-((K-1)/K)e=-((K-1)/K)[vB]. \tag{7–3}$$

For the polarization, (7–2) now gives

$$P=-E/4\pi=((K-1)/K)e/4\pi. \tag{7–4}$$

If d is the thickness of the dielectric slab, the potential difference from B to C is

$$V_{BC}=Ed=-((K-1)/K)ed. \tag{7–5}$$

If the thin conducting plates AD are introduced, as in Fig. 3(b), some of the lines of intensity will stretch continuously, as before, from the positive charges on B to the negative charges on C. The remainder will also stretch from B to C, but will proceed in three consecutive steps; namely, B to A, A to D, D to C—being rendered discontinuous by the conductors A and D. Where the lines are discontinuous there are microscopic free charges, positive and negative. But the total free charge on any finite area of the plates is zero. The introduction of the plates causes a slight increase of the polarization charges, a redistribution of the lines of intensity, and a slight strengthening of the field, purposely much exaggerated in the figure.

8. Let us now suppose the condenser AB connected by wires of negligible capacitance to a second insulated condenser EF (Fig. 4), at first with negligible capacitance. If the plates of EF are gradually brought closer together so as to increase the capacitance, the tubes of intensity E will gradually leave the region CD and will crowd more and more into the regions AC and BD, being broken in two at A and B and then proceeding from E to F. Negative and positive

[5] In this case the polarization P is the sum of two terms: $P_E\equiv(K-1)/4\pi\cdot E$, due to the action of E on the material part of the dielectric; and $P_e\equiv(K-1)/4\pi$, due to the exactly similar action of e. Thus $D\equiv E+4\pi P=E+(K-1)E+(K-1)e$, which is equivalent to Eq. (7–1).

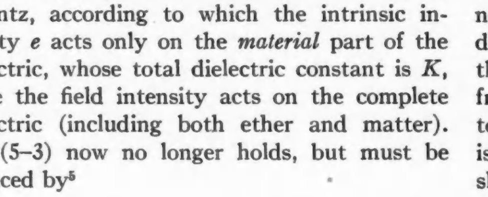


Fig. 4.

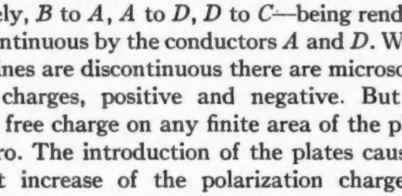


Fig. 5.

free charges thus develop on A and B; and equal positive and negative free charges on E and F. The potential difference from C to D, namely, V_{CD}, is $V_{CA}+V_{EF}+V_{BD}$. The first and third terms are negligible because the distances BD and CA are infinitesimal, so that we always have, essentially, $V_{CD}=V_{EF}$. When the plates EF touch each other, we have, finally, $V_{CD}=V_{EF}=0$. This state is illustrated in Fig. 5, where a *few* lines are drawn between C and D, although the intensity there is entirely negligible in comparison with that in the extremely thin regions CA and BD.

The polarization charges at C and D are now equal and opposite to the free charges on A and B. Within the dielectric, $E=0$, so that

$$D=(K-1)e, \tag{8-1}$$

$$P=D/4\pi=\sigma_P=(K-1)e/4\pi, \tag{8-2}$$

while on A and B the surface densities are

$$\mp\sigma_f=\mp\sigma_P=\mp(K-1)e/4\pi. \tag{8-3}$$

9. In the preceding discussion the theory of Lorentz has been assumed, according to which matter does not entrain in its motion the ether which permeates it. On the theory of Hertz, according to which the ether is completely entrained in the motion of the matter, the intensity acts on both ether and matter, so that Eq. (4–7) or (5–3) must be replaced by

$$D=K(e+E), \tag{9-1}$$

Eq. (8–1) will be replaced by

$$D=Ke, \tag{9-2}$$

(8–2) by $$P=\sigma_P=Ke/4\pi, \tag{9-3}$$

and (8–3) by $$\mp\sigma_f=\mp Ke/4\pi. \tag{9-4}$$

Thus, when the condenser is short-circuited, the charge developed on one of the plates, according to Lorentz' theory, will bear to the charge developed on the same plate according to Hertz's theory the ratio

$$Q_L/Q_H=(K-1)/K. \tag{9-7}$$

Essentially this experiment was made in 1900 by R. Blondlot,[6] with air as the moving dielectric. He could have detected readily a very much

[6] J. de Phys., Jan. (1902).

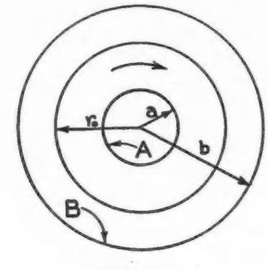


FIG. 6.

smaller charge than Q_H in his investigation, but he found no charge as great as his experimental error. The result thus favored decidedly the theory of Lorentz, as $(K-1)/K$ for air is very minute.

10. We shall now consider a still more instructive case, namely, that of a hollow insulating cylinder with thin conducting coats rotating in a uniform magnetic field with induction parallel to its axis (Fig. 6). Suppose the magnetic induction B directed inward and the rotation, ω radians/sec, right-handed, as shown. Then over any circle of radius r the motional intensity, $e=[vB]=\omega Br$, will be directed radially outward, or positive. The theory of Lorentz will be assumed.

First suppose the cylinders, of radii a and b, to be insulated from one another. Since there is no conduction between the two armatures, there can be no free charges either within the dielectric or on any area of greater than molecular dimensions on either conductor, and no flux of the vector $D=(K-1)e+KE$ across any coaxial cylinder. Thus, at any distance r from the axis,

$$e(K-1)+KE=0 \tag{10-1}$$

and

$$E=-e(K-1)/K$$
$$=-\omega B(K-1)r/K=-\alpha r, \tag{10-2}$$

where $$\alpha=\omega B(K-1)/K. \tag{10-3}$$

The polarization is

$$P=(D-E)/4\pi=0-E/4\pi=\alpha r/4\pi. \tag{10-4}$$

Consequently the polarization surface densities at the inner and outer surfaces of the dielectric are

$$_a\sigma_P=-\alpha a/4\pi \quad\text{and}\quad {}_b\sigma_P=\alpha b/4\pi. \tag{10-5}$$

Within the body of the dielectric, at the distance

r from the axis, we have

$$\operatorname{div} E=4\pi\rho=4\pi(\rho_f+\rho_P)=4\pi\rho_P, \qquad (10\text{–}6)$$

so that

$$\rho_P\equiv-\operatorname{div} P=-\frac{1}{r}\frac{\partial}{\partial r}(Pr)$$

$$=\frac{1}{4\pi r}\frac{\partial(Er)}{\partial r}=-\frac{\alpha}{2\pi}, \qquad (10\text{–}7)$$

being negative and uniform throughout. The total polarization charge within the dielectric, per unit length, is

$$\pi(b^2-a^2)\rho_P=-\tfrac{1}{2}\alpha(b^2-a^2). \qquad (10\text{–}8)$$

The sum of the total polarization charges on the inner and outer faces of the dielectric is

$$2\pi a\ {}_a\sigma_P+2\pi b\ {}_b\sigma_P=+\tfrac{1}{2}\alpha(b^2-a^2), \qquad (10\text{–}9)$$

so that the total polarization charge produced by the motion is zero, a result which, of course, could have been predicted as necessary.

The potential difference from B to A is

$$V_{BA}=-V_{AB}=-\int_a^b Edr=\int_a^b \alpha rdr$$

$$=(\alpha/2)(b^2-a^2). \qquad (10\text{–}10)$$

Now suppose the two armatures to be connected by a wire at rest. V_{AB} will be zero, so that E must change sign at a certain cylinder of radius r_0, to be determined. Within this cylinder E is positive and steadily increases as r diminishes. Outside this cylinder E is negative and steadily increases as r increases. Free charges, with surface densities ${}_a\sigma_f$ and ${}_b\sigma_f$, now exist on A and B. If ${}_aq_f$ denotes the free charge upon A, of length l, we have, from Gauss' theorem for the vector D,

$$4\pi\ {}_aq_f=2\pi rl\{\omega B(K-1)r+KE\}$$

$$=2\pi r_0 l\{\omega B(K-1)r_0\}, \qquad (10\text{–}11)$$

from which we obtain, for any radius r,

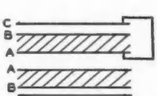


FIG. 7.

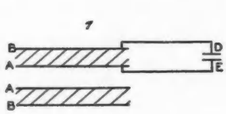


FIG. 8.

$$Er=\alpha(r_0^2-r^2) \quad \text{or} \quad E=\alpha(r_0^2-r^2)/r. \qquad (10\text{–}12)$$

From this equation and

$$\int_a^b Edr=0$$

we find

$$r_0^2=(b^2-a^2)/2\log(b/a), \qquad (10\text{–}13)$$

so that r_0 is independent of the speed, of B, and of the constant of the dielectric.

The displacement at the cylinder of radius r is

$$D=(K-1)e+KE=K\alpha r_0^2/r. \qquad (10\text{–}14)$$

Thus the densities of the free charges on the surfaces of the armatures are

$${}_a\sigma_f=D_a/4\pi=K\alpha r_0^2/4\pi a \qquad (10\text{–}15)$$

and

$${}_b\sigma_f=-D_b/4\pi=-K\alpha r_0^2/4\pi b. \qquad (10\text{–}16)$$

The polarization at the cylinder of radius r is

$$P=(D-E)/4\pi=(\alpha/4\pi r)\times\{(K-1)r_0^2+r^2\}. \qquad (10\text{–}17)$$

Hence the surface densities of the polarization charges at the inner and outer surfaces of the dielectric are

$${}_a\sigma_P=-(\alpha/4\pi a)\{(K-1)r_0^2+a^2\} \qquad (10\text{–}18)$$

and

$${}_b\sigma_P=(\alpha/4\pi b)\{(K-1)r_0^2+b^2\}. \qquad (10\text{–}19)$$

The density of the polarization charge within the body of the dielectric is

$$\rho_P=\left(\frac{1}{4\pi r}\right)\frac{\partial(Er)}{\partial r}=-\operatorname{div} P=$$

$$-\frac{1}{r}\frac{\partial(Pr)}{\partial r}=-\frac{\alpha}{2\pi} \qquad (10\text{–}20)$$

as before.

The sum of the free charges on the armatures is zero, and the sum of the volume and surface polarization charges is zero.

11. Return now to the case in which the cylinders A and B are insulated from each other, and suppose *either* that the cylinders A and B are symmetrically surrounded by a third coaxial cylinder C of the same length and that C is connected to A by a wire at rest (Fig. 7), *or* that A and B are connected by wires at rest with a condenser DE (Fig. 8). Let the capacitance of

AB, of length l, be denoted by C; that of BC or DE, by C'.

Before the addition of the extra conductors, the tubes of electrical intensity E between A and B have much the same distribution as those in Fig. 3, except that they now converge toward the axis because of the cylindrical character of the field. From the polarization charge at the outer surface of the dielectric some of the tubes (group I) proceed directly to the opposite polarization charge on the inner face; but some of the tubes (group II) pass from one polarization charge to the other by way of the conductors A and B, where they are broken in two—there being negative charges on B where the tubes strike it, and equal positive charges on A where the tubes leave it; and likewise, negative charges on A where the tubes strike it, and equal positive charges where they leave it. These charges are *free* charges.

On the addition of the conductors, a process whose result is similar to that illustrated in Fig. 4 takes place. Many of the tubes change from group I to II, and many in this second group now stretch from B to C or from D to E. The potential difference V_{BA} from B to A is now less than before. The negative free charge on the inner face of B now exceeds the positive free charge, and the positive free charge on A exceeds the negative free charge. The outer surface of B in Fig. 7 or the conductor D in Fig. 8 has a positive free charge, while C or E has an equal negative free charge. Since E within the dielectric is diminished, $D\equiv(K-1)e+KE$ is no longer zero.

Since the *total* free charge on the conductor B (or BD) is still zero, and likewise that upon A (or AE), the flux of D across a cylinder of any radius r in the dielectric in the direction AB is equal to the flux from B to C (or D to E). Thus

$$\{(K-1)e+KE\}2\pi rl=4\pi C'V. \quad (11\text{–}1)$$

Now $-KE\cdot 2\pi rl$ is the flux in the dielectric due to the free charges on A and B in the direction BA, and hence is equal to $4\pi CV$. Thus

$$(K-1)e\cdot 2\pi rl=4\pi(C'+C)V \quad (11\text{–}2)$$

and
$$e=4\pi(C'+C)V/(K-1)2\pi rl. \quad (11\text{–}3)$$

If now we integrate e from A to B, we obtain for ψ, the intrinsic emf from A to B,

$$\psi=\int_a^b edr=\frac{(b^2-a^2)\omega B}{2}=\frac{2(C'+C)V}{(K-1)l}\log\frac{b}{a} \quad (11\text{–}4)$$

$$=\frac{(C+C')V}{(K-1)l/2\log(b/a)}=\frac{(C+C')V}{((K-1)/K)C}. \quad (11\text{–}5)$$

Thus
$$V=\psi((K-1)/K)C/(C+C') \quad (11\text{–}6)$$

and the charge on D or the outer coat of B (equal and opposite to the charge on C or E) is

$$Q=C'V=\psi((K-1)/K)CC'/(C+C'). \quad (11\text{–}7)$$

12. If, instead of the theory of Lorentz, we now assume the theory of Hertz, we must replace $K-1$ in the equations of the last section by K, and thus $\alpha\equiv((K-1)/K)\omega B$ by

$$\beta=\omega B. \quad (12\text{–}1)$$

Otherwise the equations remain unchanged. Thus in place of Eqs. (11–6) and (11–7) we obtain

$$V_H=\psi C/(C+C') \quad (12\text{–}2)$$

and
$$Q_H=\psi CC'/(C+C'). \quad (12\text{–}3)$$

Thus we have

$$V/V_H=Q/Q_H=(K-1)/K. \quad (12\text{–}4)$$

13. Let us now substitute for the insulating cylinder of Section 10 and its conducting armatures a conducting cylinder with the same internal and external radii a and b. Positive electricity within the conductor (if it is free to move) will be displaced outward, and negative electricity (if it is free to move) will be displaced inward, until a steady state is reached in which at any point of the electrical field now within the conductor the total force on any particle of electricity vanishes. That is, at any point distant r from the axis

$$e+E=0 \quad (13\text{–}1)$$

or
$$E=-e=-\omega Br=-\beta r. \quad (13\text{–}2)$$

Instead of a polarization charge within the cylinder there is now a free charge, whose density is

$$\rho_f=\text{div}\,E/4\pi=(1/4\pi r)\partial(Er)/\partial r$$
$$=-\beta/2\pi. \quad (13\text{–}3)$$

At the outer and inner surfaces there are now

free charges with the densities

$$ {}_b\sigma_f = -E_b/4\pi = \beta b/4\pi \tag{13–4} $$

and

$$ {}_a\sigma_f = E_a/4\pi = -\beta a/4\pi. \tag{13–5} $$

The total charges on unit lengths of the outer and inner surfaces are ${}_bQ_f = \beta b^2/2$ and ${}_aQ_f = -\beta a^2/2$, whose sum is

$$ {}_bQ_f + {}_aQ_f = \tfrac{1}{2}\beta(b^2 - a^2), \tag{13–6} $$

which is just equal and opposite so the volume charge within unit length of the cylinder; namely,

$$ Q_{\mathrm{vol}} = \rho_f \pi (b^2 - a^2) = -\tfrac{1}{2}\beta(b^2 - a^2). \tag{13–7} $$

The potential difference from the outer to the inner surface is

$$ V_{BA} = -\int_a^b E dr = \tfrac{1}{2}\beta(b^2 - a^2). \tag{13–8} $$

All these results clearly follow also from the corresponding results of Section 10 by making $K = \infty$, when $\alpha \equiv ((K-1)/K)\omega B = \omega B \equiv \beta$, and the polarization charges become free.

14. The experiments of Blondlot on air, for which $K-1$ is only a minute fraction of unity, have already been described as confirming the theory of Lorentz. The importance of experiments in which $K-1$ is a considerable fraction of K led the author[7] in 1902, and H. A. Wilson[8] in 1903, to begin investigations in which solid dielectrics were used. In the latter's work the dielectric was in the form of a hollow cylinder of ebonite and his procedure was equivalent to measuring the potential difference equal to V in Eq. (11–6) on the theory of Lorentz, or to V_H in Eq. (12–2) on that of Hertz. In the author's work, completed in 1908, a much more extensive investigation was made, on cylinders of ebonite, sulfur, and two kinds of rosin; the procedure was equivalent to measuring the charge equal to Q in Eq. (11–7) on the theory of Lorentz, or to Q_H in Eq. (12–3) on that of Hertz. All the results confirm the theory of Lorentz, according to which the dielectric does not entrain the ether in its motion.

[7] Phys. Rev. **27**, 425–472 (1908).
[8] Phil. Trans. Roy. Soc. **A204**, 121 (1905).

Partly Unbalanced Processes and the Experiment of Clément and Desormes

Morton Masius
Department of Physics, Worcester Polytechnic Institute, Worcester, Massachusetts

The volume changes of gases that are considered in the classical theory of thermodynamics are usually either free expansions, into a vacuum, as in the experiments of Gay-Lussac and Joule, or directly reversible expansions, completely balanced, so that the pressure *of* the gas differs from the pressure *on* it merely by an infinitesimal amount, as in the steps of a reversible Carnot cycle. In the former case the expanding gas does no work on the surroundings; in the latter, the work may be obtained by taking the value of $\int p dv$ between appropriate limits. All expansions of gases that actually occur in nature are neither entirely free nor entirely balanced expansions, but intermediate, partly unbalanced ones. The purpose of this paper is to consider the relations that hold for *adiabatic*, partly unbalanced expansions and to apply them to an illustrative example, namely, the experiment of Clément and Desormes.

Adiabatic Expansion Against Constant Pressure

It will be assumed that the gas is an ideal gas, so that the equation of state, in the notation of Planck's thermodynamics, becomes

$$ pv = RT/m, \tag{1} $$

in which v is the specific volume and m is the mass of a mole. For an ideal gas, c_v, the specific heat at constant volume, is constant,[1] the relation

[1] M. Planck, *Thermodynamik* (Barth, ed. 9, 1930), §§ 86–88.

$$R/m = c_p - c_v \tag{2}$$

is correct, and the energy of the gas, per unit mass, is given by

$$u = \int du = \int c_v dT. \tag{3}$$

In order to visualize conveniently the process to be considered, the gas may be thought of provisionally as being in a vertical cylinder that is closed part way down by a weighted piston; and the space above the piston may be regarded as evacuated, so that the pressure on the gas is caused by the weighted piston alone. The initial equilibrium condition of the gas is determined by the two variables of state p_0 and T_0, where p_0 is the ratio of the weight of the piston itself and the extra weight on it and its cross-sectional area. The extra weight is now removed and the final state of the gas is to be determined by the pressure p, due to the piston alone, and the condition that during the expansion the gas is not to exchange any heat with the surroundings.

Since at the instant when the extra weight is removed the pressure p_0 of the gas exceeds the pressure p due to the piston by a finite amount, the piston will have an accelerated motion, acquire some kinetic energy, and by virtue of it pass beyond the new equilibrium position and then oscillate. Even if it is assumed for simplicity that the piston moves without friction, the oscillations will gradually die out, for in the alternate changes which occur in the gas from the kinetic energy of a directed surge stream to the kinetic energy of the chaotic heat motion of the molecules, there will be a tendency for the directed motion to disappear. Eventually, then, the gas will reach a new equilibrium position in which the values of the variables of state are p and T.

The value of T may be calculated from the given conditions of the problem. The assumption that the process is adiabatic leads to the equation,

$$u_0 - u = c_v(T_0 - T) = p(v - v_0),$$

in which the term $c_v(T_0 - T)$ represents the energy change of unit mass of the gas, and the term $p(v - v_0)$ the work done per unit mass in overcoming the constant pressure p.

If the specific volumes are expressed in terms of pressures and temperatures by Eq. (1), and the term R/m is expressed in terms of specific heats by Eq. (2), the result is

$$c_v(T_0 - T) = (c_p - c_v)p\left(\frac{T}{p} - \frac{T_0}{p_0}\right)$$
$$= c_v(\gamma - 1)p\left(\frac{T}{p} - \frac{T_0}{p_0}\right),$$

where γ represents the ratio c_p/c_v. This yields for T,

$$T = (T_0/\gamma)[1 + (\gamma - 1)(p/p_0)].$$

A more symmetrical form is readily obtained by simple transformations; it is

$$(T_0 - T)/T_0 = (\gamma - 1)(p_0 - p)/\gamma p_0. \tag{4}$$

This simple linear equation in p and T shows clearly the contrast with the well-known equation

$$dT/T = (\gamma - 1)dp/\gamma p$$

for reversible adiabatic changes.

The difference between the equation of state for reversible adiabatic changes, which is obtained by integration from the last equation, lies not merely in the different functional relation between p and T, but also in the fact that the equation of state for reversible adiabatic changes applies not only to the initial and final states of the process but to the intermediate states as well. Eq. (4), however, establishes only a relation between the original and the final state. During the intermediate stages there are local temporary changes in temperature and pressure that make it impossible to assign any definite values to pressure and temperature of the gas as a whole.

If Eq. (4) is re-expressed in terms of pressure and volume, it becomes

$$(p_0 - p)/p = -\gamma(v_0 - v)/v_0 \tag{5a}$$

while, in terms of temperature and volume, it is

$$(T_0 - T)/T = -(\gamma - 1)(v_0 - v)/v, \tag{5b}$$

as contrasted with the corresponding equations for reversible adiabatic processes,

$$dp/p = -\gamma dv/v$$

and $$dT/T = -(\gamma-1)dv/v.$$

Eqs. (5a) and (5b), however, are not as simple as Eq. (4), for they are not linear.

If these relations are to be applied when p is small, this small value of p must be maintained throughout the expansion. When, either because p is small, or because p_0 is large, the ratio p/p_0 is very small compared with unity, the value of v becomes very nearly $v_0 p_0/\gamma p$, and the value of T approaches T_0/γ. It is perhaps not entirely beyond the range of experimental possibility to use the large cooling of the gas in this case for a determination of γ.

Since the expansion against constant pressure is not completely reversible, there will be some increase in entropy. A convenient method of calculating it is to replace the actual process by a fictitious two-step process, in which the first step is taken as a reversible adiabatic to a properly selected intermediate condition in which the temperature is T, the specific volume ϕ, and the pressure π. This is to be followed by a free expansion to the final condition T, v, p. Since there is no change in entropy during the first (reversible) step of the two-step process, and since the temperature is the same at the beginning of the second (irreversible) step as at the end, the entropy change per unit mass is given by

$$S_2 - S_1 = (R/m)\lg (v/\phi)$$

or, if the relative change in volume during the second step is denoted by q, so that

$$q = (v-\phi)/\phi = (v/\phi) - 1,$$

by

$$S_2 - S_1 = (R/m)\lg(1+q). \tag{6}$$

Since, by the ordinary pressure temperature relation of a reversible adiabatic,

$$\pi = p_0(T/T_0)^{\gamma/\gamma-1},$$

and, since the intermediate and final temperatures are the same,

$$vp = \phi\pi,$$

q, in terms of pressure and temperature becomes

$$q = (p_0/p)(T/T_0)^{\gamma/\gamma-1} - 1.$$

If, as is the case in the illustrative example given below, the temperature change, say t, is small, a sufficient approximation is obtained if the expression

$$\left(\frac{T}{T_0}\right)^{\gamma/\gamma-1} = \left(\frac{T_0 - t}{T_0}\right)^{\gamma/\gamma-1} = \left(1 - \frac{t}{T_0}\right)^{\gamma/\gamma-1}$$

is expanded to the second power of the small quantity t/T_0:

$$\left(\frac{T}{T_0}\right)^{\gamma/\gamma-1} = 1 - \frac{\gamma}{\gamma-1}\frac{t}{T_0} + \frac{\gamma}{2(\gamma-1)^2}\frac{t^2}{T_0^2}.$$

Since, from Eq. (4),

$$\frac{p}{p_0} = 1 - \frac{t}{T_0}\frac{\gamma}{(\gamma-1)},$$

q, in terms of temperatures only, reduces to

$$q = \left[\frac{\gamma t^2}{2(\gamma-1)^2 T_0^2}\right] \Big/ \left[1 - \frac{\gamma t}{(\gamma-1)T_0}\right]$$

$$= \frac{\gamma t^2}{2(\gamma-1)T_0[(\gamma-1)T_0 - \gamma t]}$$

or, with sufficient accuracy, to

$$q \doteq \gamma t^2/2(\gamma-1)^2 T_0^2. \tag{7}$$

If, on the other hand, the temperatures are eliminated by Eq. (4), q, in terms of pressures only, becomes

$$q \doteq (p_0 - p)^2/2\gamma p_0^2. \tag{8}$$

The last two small values of q permit a convenient expansion of the term $\lg(1+q)$ in Eq. (6), and, since $\lg(1+q) \doteq q$, yield for the entropy change in terms of temperature and pressure, respectively,

$$S_2 - S_1 = \left(\frac{R}{2m}\right)\frac{\gamma(T_0 - T)^2}{(\gamma-1)^2 T_0^2}$$

and $$S_2 - S_1 = \left(\frac{R}{2m}\right)\frac{(p_0 - p)^2}{\gamma p_0^2}.$$

The Experiment of Clément and Desormes

The pressure in the room is p, and the gas in a carboy is at a higher pressure $p_0 = p + x$ and at the temperature of the room T_0. The gas is

now suddenly released, it expands to the pressure p and the specific volume v, and then the carboy is closed again. The gas, which has been cooled by the expansion to a lower temperature $T=T_0-t$, returns to the initial temperature T_0 and reaches the final pressure $p'=p+y$.

If now the assumptions are made that (1) the gas is ideal, (2) the expansion is truly adiabatic, (3) the carboy is closed again at the right instant, and (4) the expansion is reversible, then, since

$$p_0v_0=p'v', \tag{9}$$

$$p_0v_0{}^\gamma=pv^\gamma, \tag{10}$$

$$v=v', \tag{11}$$

the value of γ is found to be

$$\gamma=\frac{\lg (p_0/p)}{\lg (p_0/p')}=\frac{\lg (1+x/p)}{\lg (1+(x-y)/(p+y))}.$$

This value, obtained from the classical theory, will hereafter be denoted by λ to distinguish it from another value of γ to be taken up presently. Thus

$$\lambda=\frac{\lg (1+x/p)}{\lg (1+(x-y)/(p+y))}. \tag{12}$$

If, now the first three assumptions are retained, but the fourth is replaced by the assumption, presumably nearer the truth, that the expansion takes place against a constant pressure p, Eq. (10) is replaced by Eq. (5a), and, from Eqs. (9), (5a) and (11), γ is found to be

$$\gamma=\frac{x(p+y)}{(x-y)p}=1+\frac{(p+x)y}{p(x-y)}=\frac{p+y}{p}\left(1+\frac{y}{x-y}\right). \tag{13}$$

So long as the initial pressure $p+x$ is only slightly larger than p, and hence the ratio x/p, and therefore also y/p, is small compared with unity, the work done in an expansion against a constant pressure p differs little from the work done in a reversible expansion during which the pressure decreases from $p+x$ to p. Accordingly, for sufficiently small values of x/p the value of γ from Eq. (13) should agree very nearly with the value of λ from Eq. (12). In fact, if the logarithms in Eq. (12) are expanded into a power series to the first powers of small quantities only, the result is

$$\lambda'=x(p+y)/p(x-y), \tag{14}$$

which agrees with the value of γ from Eq. (13). It should be noted, however, that according to the usual theory of the experiment, which assumes a reversible expansion, the *exact* value of λ is given by Eq. (12), and the λ' in Eq. (14) is only a good approximation. On the other hand, according to the theory of expansion against constant pressure, the λ' in Eq. (14), which agrees with γ from Eq. (13), is the *exact* value.

The relative difference of γ and λ,

$$\frac{\gamma-\lambda}{\gamma}=\left[\frac{x(p+y)}{(x-y)p}-\frac{\lg (1+x/p)}{\lg (1+(x-y)/(p+y))}\right]\times\left[\frac{1}{x(p+y)/(x-y)p}\right], \tag{15}$$

may now be obtained with sufficient accuracy, so long as x remains small compared with p, by expanding the logarithms in Eq. (12) and carrying the expansion to the second powers of small quantities. After the introduction of

$$\lg (1+x/p)=x/p-x^2/2p^2$$

and

$$\lg (1+(x-y)/(p+y))=(x-y)/(p+y)-(x-y)^2/2(p+y)^2,$$

and a few reductions, the final result is

$$(\gamma-\lambda)/\gamma=y(p+x)/p(2p+3y-x)\doteq y/2p. \tag{16}$$

In spite of the fact that the original experiment of Clément and Desormes, in which γ was obtained from readings of pressure, was improved by later investigators, including experimenters of the rank of Kohlrausch and Röntgen, it is now generally believed that the temperature modification of the experiment, introduced by Lummer and Pringsheim, is more likely to give accurate results.[2] The classical theory of this method, on the assumption of a reversible expansion, leads to the result

[2] For complete bibliography and discussion of methods and results, see Partington and Shilling, *The Specific Heats of Gases* (Van Nostrand, 1924).

$$\lambda = \frac{\lg p_0/p}{\lg p_0/p - \lg T_0/T} \tag{17}$$

while, on the assumption of expansion against constant pressure—that is, by Eq. (4)—the value of γ is found to be

$$\gamma = \frac{(1-p/p_0)}{(T/T_0 - p/p_0)}. \tag{18}$$

Since, during the last step of the original experiment, the specific volume $v(=v')$ remains constant, the corresponding pressures and temperatures are proportional; that is,

$$T/T_0 = p/(p+y)$$

or

$$(T_0 - T)/T_0 = t/T_0 = y/(p+y);$$

and hence it is readily seen that λ from Eq. (17) is equivalent to λ from (12), and γ from Eq. (18) is equivalent to γ from (13). Thus the relative difference of γ and λ is the same as calculated in Eq. (16), or, in terms of temperature, with sufficient accuracy

$$(\gamma - \lambda)/\gamma = t/2T_0. \tag{19}$$

In the experiments of Röntgen the relative excess pressure was never more than 0.021, which, according to Eq. (4), for a gas for which γ is 1.4, corresponds to a relative temperature change t/T_0 of no more than 0.006. Hence, by Eq. (17), the value of γ, the ratio of the specific heats, exceeds λ, the value of the ratio calculated in the usual manner, by no more than

$$\gamma - \lambda = \gamma t/2T_0 = 0.005,$$

while in the experiments of Lummer and Pringsheim, where t/T_0 usually was about 0.03, the difference of γ and λ might exceed 0.02. Thus the customary value of λ would give too small a value for the ratio of the specific heats.

Since the expansion against constant pressure is not quite reversible, the escaping gas will have some kinetic energy which is necessarily furnished by the remaining gas. The temperature of the latter will therefore be temporarily lowered, and a thermometer of very small thermal capacity and with no lag should register this temperature lowering. This effect would always tend to make λ too large. For if the effect of a small change in the value of T on the value of λ is calculated from Eq. (17), it is found to be, with sufficient accuracy,

$$d\lambda = -\gamma(\gamma - 1)dT/t, \tag{20}$$

so that any decrease in T produces an increase in λ.

An attempt to make a calculation of the possible maximum temporary change leads to very complicated considerations, and if too many simplifying assumptions are made in the calculation, the result is of no value. It is certain, however, that the temporary drop must be very small. For it is caused by the fact that, the external pressure at the beginning of the expansion being less than the pressure of the gas, the expansion is slightly irreversible. The value of q, Eq. (8), for Röntgen's experiments is only of the order of magnitude 1.4×10^{-4}, however. Hence the departure from a reversible expansion is very slight. Even with the much larger excess pressure used by Lummer and Pringsheim, the value of q calculated from Eq. (7) is only about 0.003. This small value of q indicates that a reversible expansion, with no surging motion at all, would have produced an expansion very nearly equal to the actual expansion. Thus, since the actual expansion, with the surging motion and the temporary temperature drop, goes only *very slightly* beyond a reversible expansion with no such effect, the effect must be very small.

Fall Meeting of the Kentucky Chapter

The Kentucky Chapter of the American Association of Physics Teachers met at the University of Kentucky on October 29, in connection with the Annual Education Conference and the annual meeting of the Kentucky Association of Colleges and Secondary Schools. The program consisted of two addresses: "Physics in the High School," by Professor Guy Forman, Western Kentucky State Teachers College; and "Teaching Physics for Culture," by Professor W. S. Webb, University of Kentucky. Professor A. D. Hummell, president of the chapter, presided. The meeting closed with a luncheon.

A Scheme for Correlating Nuclear Data*

JAMES J. BRADY
Department of Physics, Oregon State College, Corvallis, Oregon

THE following scheme is suggested as a teaching aid in correlating nuclear data pertaining to the lighter elements, to be used until a more accurate picture is developed.[1] By means of a purely qualitative energy diagram and a set of five very simple rules, questions may be readily answered as to the number of isotopes associated with a given atomic number, the relative stability of isotopes, the radioactive properties of a given nucleus and, if radioactive, whether an electron or a positron is emitted.

The energy level diagram is shown in Fig. 1. To facilitate drawing the diagram, the following convenient dimensions are suggested: for the proton levels, 1 in. between levels *1* and *3*, *3* and *5*, etc., and $\frac{1}{4}$ in. between *1* and *2*, *3* and *4*, etc.; for the neutron levels, level *1*, $\frac{1}{16}$ in. above proton level *1*; then, $\frac{29}{32}$ in. between levels *1* and *3*, *3* and *5*, etc.; and $\frac{1}{4}$ in. between levels *1* and *2*, *3* and *4*, and so on. Assume only one particle for each energy level. The number of filled proton levels gives the atomic number of the element, and the sum of the filled proton and filled neutron levels gives its atomic weight. The abundance of an isotope in nature is taken as the criterion of its stability.

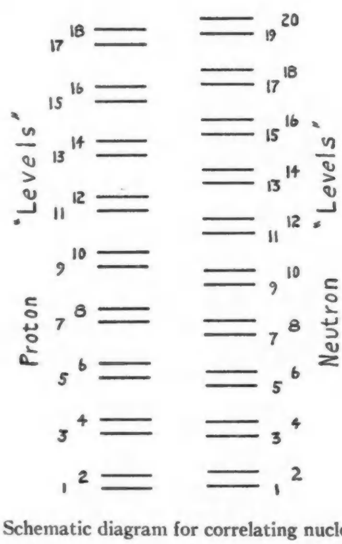


FIG. 1. Schematic diagram for correlating nuclear data.

The five rules for building up a nucleus are:

1. For a stable nucleus, the lowest energy levels must be filled first.

2. The *most* stable nuclei are those that have an even atomic number and are made up of equal numbers of protons and neutrons.

3. For greatest stability, if the number of *protons* is *odd*, the number of neutrons is even.

4. When the number of protons is *even*, the nuclei of greatest stability will be those that have an *even* number of neutrons.

5. A proton may pass to a lower neutron level by giving off a positron, and a neutron may pass to a lower proton level by giving off an electron.

The scheme will now be illustrated by building up different nuclei.

Consider first the deuteron—one proton and one neutron. If one more neutron were added, the result would be H^3; proton level *2*, which lies below neutron level *2* on the diagram, would be empty. By rule 1, H^3 would not be expected to be stable.[2] He^3 and He^5 should be stable according to this scheme. By rule 4, however, the most stable atoms are those in which the levels fill up in pairs; consequently, one would not expect to find very great stability in He^3 and He^5. By rule 2, He^4 should be extremely stable.

He^6 should not be stable because that would leave a vacancy lower down in proton level *3*; so the next stable nucleus would be Li^6. Li^7 should be more stable according to rule 3. In nature these are found in percentages: Li^6, 7.9; Li^7, 72.1.

According to the scheme, Be^8 should be a very stable isotope. It is not, however, and is one of the outstanding exceptions to the scheme. Be^9 should be stable, and it is. Both B^{10} and B^{11} should be stable, with B^{11} being the more common, which is correct. C^{12} is a case of an even atomic number, and the number of neutrons is equal to the num-

* Published with the approval of the Monographs Publication Committee, Oregon State College. Research paper No. 12, Department of Physics, School of Science.

1 The scheme works as well as it does because of the saturation character of nuclear forces; this point of view is stated in the beginning of the article by Bethe and Bacher, Rev. Mod. Phys. **8**, 82 (1936). Although the scheme has been found useful in presenting a plausible picture of the nucleus to undergraduate students in modern physics, it should be emphasized, of course, that it is purely empirical except for the point about the saturation character of nuclear forces.

2 R. Sherr, L. G. Smith and W. Bleakney (Phys. Rev. **54**, 388 (1938)) have recently reported from the results of their experiments that H^3 may be unstable. This suggestion was made earlier by Bonner, Phys. Rev. **53**, 711 (1938).

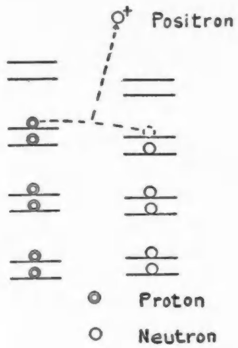


FIG. 2. Radioactive carbon.

ber of protons—a very stable isotope. C^{13} should exist as a stable isotope, and it does.

The next vacancy on the energy diagram is proton level 7. This gives rise to N^{14}, but, according to the rules, N^{15} should be more stable. This prediction is another discrepancy in the scheme as N^{14} is much more abundant in nature than N^{15}.

O^{16} is, of course, a very stable isotope (rule 2).

O^{17} and O^{18} should also be stable, with O^{18} being more stable than O^{17} because it represents a "filled pair" of neutron levels (rule 4). Thus, the three stable isotopes of oxygen fit into the scheme.

The next vacant energy level is proton level *9* with the neutron levels filled with ten neutrons. This is F^{19}. Fig. 1 shows that this can be the only stable isotope of fluorine, and no others have ever been found in nature.

The next vacant level is proton level *10*, which is the nucleus Ne^{20}. One would expect this to be exceptionally stable (rule 2), and it is. One would expect, also, that Ne^{21} and Ne^{22} would be found in nature, and they are, Ne^{22} being much more common than Ne^{21} (in agreement with rule 4).

The next nucleus is Na^{23}. It should be the only stable nucleus of sodium as the next vacant neutron level lies above the next vacant proton level. This agrees with what is found in nature.

The three isotopes of magnesium are predicted from the diagram.

Al^{27} has no stable isotopes, and this is what one would predict from Fig. 1.

The three isotopes of silicon are also predicted, but the abundance of Si^{29}, with respect to Si^{30}, is in violation of rule 4.

P^{31} has no stable isotopes.

Chlorine has just two isotopes, as is shown by the diagram. However, the simple scheme here outlined would have to be altered to account for the heavier isotopes.

Up to this point, only the stable isotopes have been considered. The scheme is equally successful in visualizing the reactions from radioactive isotopes.

According to Crane and Lauritsen[3] C^{12}, when bombarded with high energy neutrons, emits two neutrons. This leaves the radioactive isotope C^{11}. According to Fig. 2, neutron level *6* is vacant, in violation of rule 1 for a stable isotope. One would expect, then, that C^{11} would emit a positron while proton level *6* is being evacuated and neutron level *6* is being filled. This radioactive isotope in fact *does* emit positrons.

A similar reaction occurs in the case of nitrogen where the radioactive isotope is N^{13}. Here neutron level *7* is

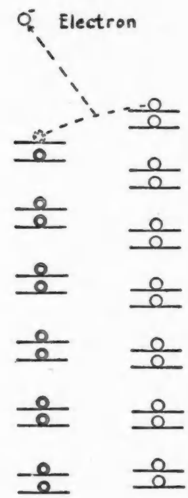


FIG. 3. Radioactive sodium.

vacant, and lies lower on the energy diagram than proton level 7. Here again a positron is emitted with a resulting stable nucleus, C^{13}, being formed.

In the case of sodium bombarded with high speed neutrons, the radioactive isotope is Na^{24}. One can see from Fig. 3 that proton level *12* is vacant and lies lower than neutron level *13*. The result is a transformation of a neutron from its level *13* to a proton in level *12*—with the ejection of an electron. Experimentally, the radioactive isotope is known to emit β-particles.

All of the reactions from artificially radioactive substances fit into this scheme.

In conclusion, it might be well to point out that the most glaring exception to this scheme, Be^{8}, has just the right number of particles to form two α-particles and that this may be responsible for its *comparative* instability. That would leave N^{14} and N^{15} as the only other serious exception. The case of the relative abundance of Si^{29} and Si^{30} is not serious since there is very little difference in their relative abundance.

[3] Phys. Rev. **45**, 430 (1934).

Radio Units for the Laboratory

Paul A. Northrop
Department of Physics, Vassar College, Poughkeepsie, New York

MANY teachers have wished to use radio as a tool for the teaching of electrical principles and their applications. This seems worth while, for one finds many phenomena illustrated which vary in difficulty from those described by Ohm's law to those involved in coupled circuits. Familiarity with this field is also of importance because the methods developed in radio are being applied to other sciences and to industrial problems in rapidly increasing number. A teacher who attempts to use radio material in the laboratory usually finds, however, that only the more elementary principles can be studied effectively in the time available to the student. For the purpose of saving much of the student's time that is spent in making electrical connections, and yet providing apparatus that can be simply and intelligently manipulated, the writer has constructed a number of units which can be studied separately or combined quickly to form various types of radio sets.

These units are constructed with open wiring upon a baseboard with only enough paneling to carry the necessary controls, thus making it possible to trace the connections with comparative ease. In addition, circuit diagrams of the units have been prepared so that, if the diagrams are laid side by side, the proper connections between the corresponding units and the functioning of the assembly can be ascertained readily. Thus a superheterodyne for use on direct current and its circuit may be assembled with ease from Units 5, 6, 7, 8, 12, and their diagrams as illustrated in Fig. 1. It may be arranged for use on either alternating or direct current by adding the rectifier of Unit 9 (Fig. 9), or, for use on alternating current alone, by substituting the rectifier of Unit 10 (Fig. 10) for that of Unit 9, connecting the heaters in parallel instead of series, and substituting a 6L6 for the 25L6 as an output tube. If the heaters are operated in series, the binding posts H_1 and H_2 in the various units are sufficient; but for parallel operation the other binding posts H are necessary. Octal base tubes were selected for this apparatus because there seem to be more different kinds of tubes using this base than any other single type.

A study of the accompanying diagrams will reveal that, in the use of this apparatus, there remain enough decisions to be made by the

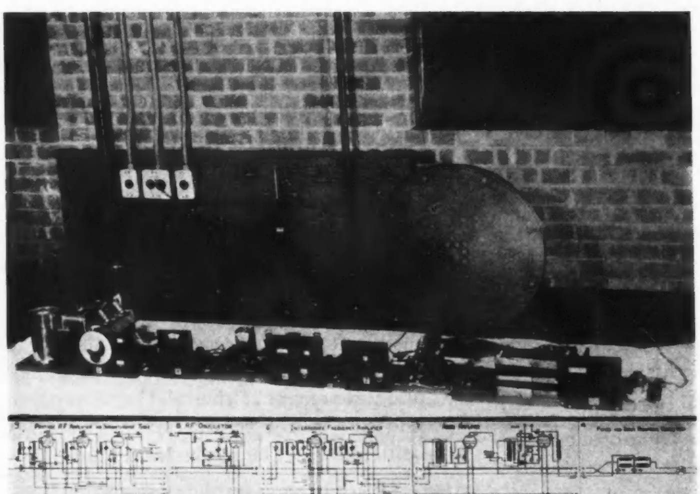


Fig. 1. A typical assembly. The diagrams which appear at the bottom of the photograph are those for the units involved; namely, Units 5, 6, 7, 8 and 12.

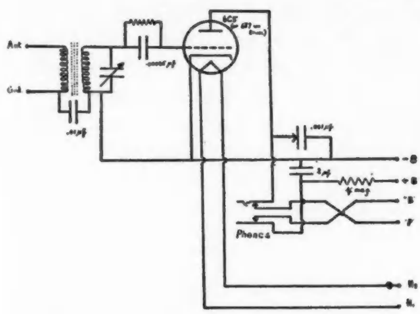


FIG. 2. Grid leak and condenser detector.

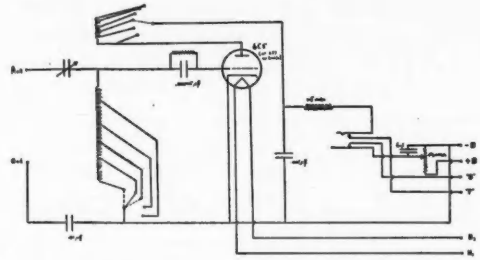


FIG. 3. Regenerative or nonregenerative detector.

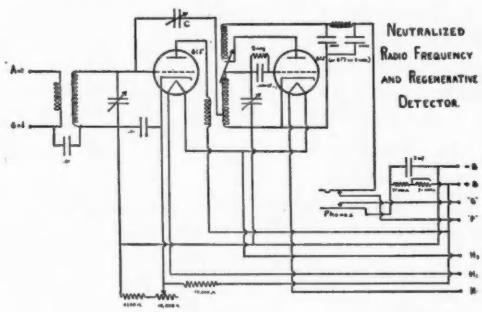


FIG. 4. Neutralized R.F. and regenerative detector.

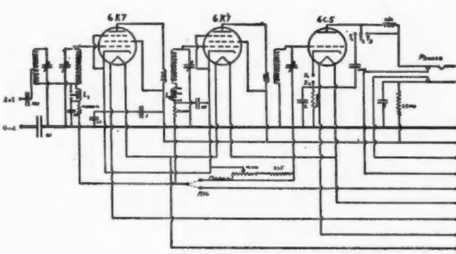


FIG. 5. Pentode R.F. and superheterodyne tuner.

student so that thoughtful work is necessary. There is also an obvious advantage in fixing in the student's mind the essential units or components of any particular circuit and the functional relation between them, thereby eliminating the vagueness which might arise from attention to too many details in construction. The following brief descriptions of the units may be of interest.

Figure 2. This grid leak and condenser detector uses an inductance with an iron-dust core; it forms a fairly selective, though relatively insensitive, receiver.

Figure 3. The antenna is a part of the tuned circuit in this regenerative (or nonregenerative) grid leak and condenser detector, thus providing good sensitivity and reasonable selectivity. If the antenna and ground binding posts are bussed together and a separate inductance is used to transfer energy from the antenna to the tuned circuit, the receiver will resemble the more usual arrangement of the preceding unit and will cover a greater frequency range for a particular value of tuning inductance.

Figure 4. The 6C5 used as a radiofrequency amplifier is "neutralized" by means of the condenser *C*. (In Units 2, 3 and 4, provisions are made so that a 6J7 may be used as a triode instead of the 6C5, with a resultant decrease in the electrical disturbances transferred through the capacitance existing between the heater and grid leads in the 6C5; this is particularly important with grid leak and condenser detectors because of the high audio-impedance between the grid and cathode.)

Figure 5. Two stages of pentode radiofrequency amplification and a grid bias detector are used in a circuit which may be used alone or as part of a superheterodyne. In the former case the binding posts X_1 and X_2 are connected, and also Y_1 and Y_2. In the latter case the necessary heterodyning frequency is injected at X_1 and X_2 while Y_2 and Y_3 are connected to remove the radiofrequency choke from the circuit and avoid by-passing part of the intermediate frequency signal through the condenser. The two tuned circuits in the antenna stage may be loosely or closely coupled by shorting out more or less of the inductance L_1 which is common to both, thus altering the selectivity of this stage. The frequency to which

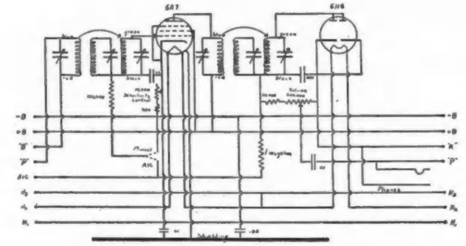


FIG. 6. Intermediate frequency amplifier.

the tuned circuit of the second stage resonates for a given setting of its condenser may also be varied by shorting out part of the inductance L_2. The four condensers are tuned by a single control. The automatic volume control *AVC* functions only when this unit is used as part of the superheterodyne.

Figure 6. In this one-stage intermediate frequency amplifier and diode detector, the coupling between stages is effected by means of three tuned circuits using iron-dust core inductances, the center inductance of which can be rotated to provide variable coupling between the other two tuned circuits. Oscillograms showing the response of this unit when (a) the coupling in each unit is a minimum, (b) the coupling of the second stage is the maximum provided for, and that of the first stage is as great as is possible without introducing asymmetry into the resonance curve, (c) the coupling of the first stage is also increased to the maximum value provided for, are shown in Figs. 6(a), 6(b) and 6(c), respectively. These were made using a double sweep oscillator and a 3-in. oscillograph.

Figure 7. The audio-amplifier unit offers the choice of: (*A*) no inverse feedback; (*B*) inverse feedback using a 0.005-μf condenser which becomes ineffective at a frequency of about 200 cycle/sec; (*C*) inverse feedback using a 0.055-μf condenser which is effective over the audiorange tested, greatly reducing the sensitivity but increasing the fidelity of the unit. These effects are illustrated in curves *A*, *B*, *C*, respectively, Fig. 7(a).

Figure 8. The radiofrequency oscillator may be used to provide the heterodyning frequency for the superheterodyne circuit. By varying the capacitance of the padding condenser *C* and the

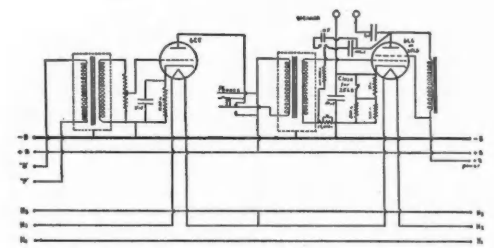


FIG. 7. Audio-amplifier.

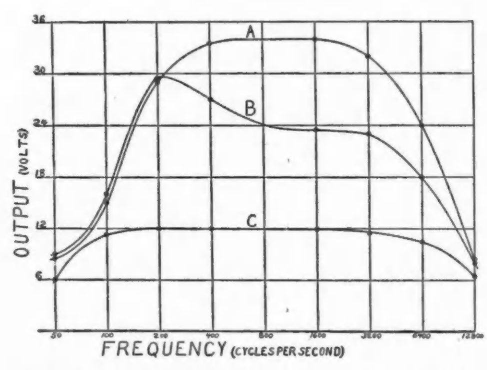
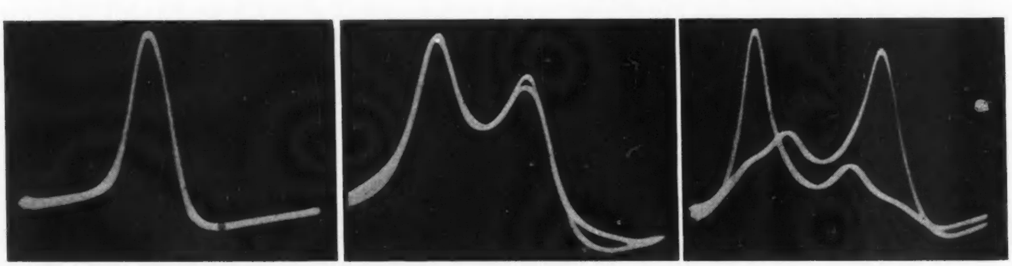


FIG. 7(a). Graph of output *vs* frequency, for Unit 7.



(a) (b) (c)

FIG. 6(a), (b), (c). Oscillograms showing responses for Unit 6.

inductance L (the latter accomplished by adjusting the position of an iron-dust core), the effect of these on the accuracy of tracking of the tuning condenser with those of Unit 5 may be observed.

Figure 9. The two 25Z5 rectifier tubes used in parallel as voltage doublers will supply 200 ma at 200 v when used on 110-v a.c. Switch S_2 makes it possible to use only one tube at half the current output, while S_3 and S_4 enable either tube to rectify on one-half of the wave alone and thus charge only one of the 40-μf condensers across the output.

Figure 10. Switch S_1 removes the 8-μf filter condenser from the circuit of this rectifier if a choke input filter is desired, while S_2 converts

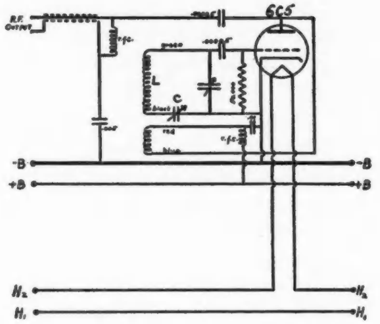


FIG. 8. Radiofrequency oscillator.

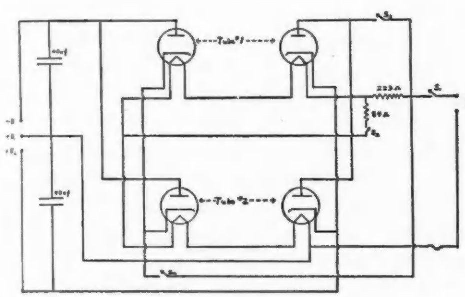


FIG. 9. Rectifier and voltage doubler.

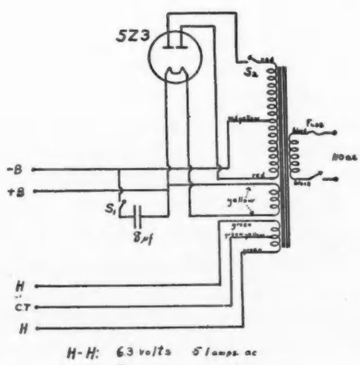


FIG. 10. Rectifier.

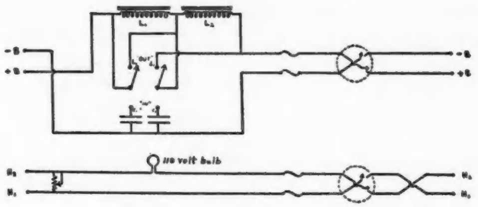


FIG. 11. Filter and series-heater current control.

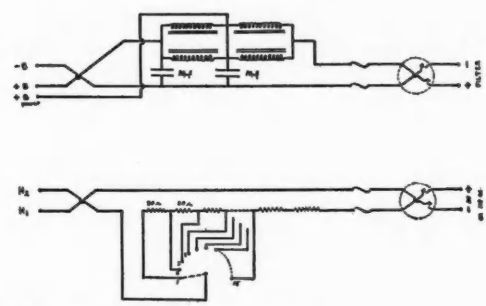


FIG. 12. Filter and series-heater current control.

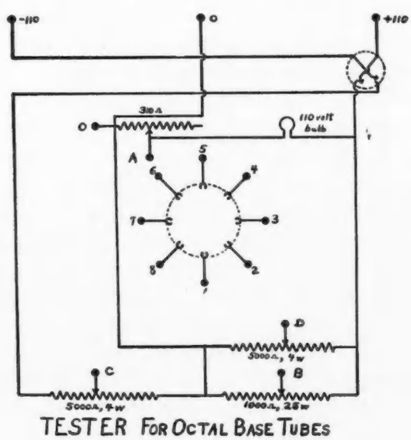


FIG. 13. Tester for octal base tubes.

the rectifier into a half-wave rectifier. These switches are also convenient if an oscillogram of the unfiltered rectified waves is desired.

Figures 11 and 12. These units provide filtering for d.c. or rectified a.c. and also make it possible to adjust the heater currents if the tubes are connected in series. On Unit 12 the 15-point switch includes enough 20-ohm resistances in the circuit to permit a current of 0.3 amp in the series-connected heaters of 1 to 15 tubes of the usual 0.3-amp, 6.3-v rating.

Figure 13. This tester which is used on a 220-v, 3-wire d.c. system has proved useful for determining the characteristics of octal base tubes.

In addition, a low power radiofrequency oscillator which can be voice modulated is planned for this series of units.

The performance of the units themselves and of the more complicated sets constructed from them has been highly satisfactory. The experiments which can be performed vary in difficulty and have been found suitable for students at different stages of their advancement.

The Physics Problem in Secondary Schools

Roy W. McHenry
Santa Monica High School, Santa Monica, California

An attempt is made in this paper to present the principal difficulties encountered in teaching physics in secondary schools and to suggest some possible solutions. Many college instructors have the responsibility of helping to train prospective secondary school teachers, and it is desirable that they be aware of the problems which the latter will have to face.

Perhaps the first problem which confronts the beginning secondary school teacher is the appalling lack of laboratory and demonstration equipment. In the university he has been accustomed to draw whatever materials were necessary from the stock room and to proceed merrily on his way. In the secondary school he must be more ingenious, for in many of the schools he is indeed fortunate if there is a single set of laboratory equipment for each experiment. In the typical case, the funds available for new apparatus are so limited that the teacher has the choice of having several experiments covering different principles under way at the same time, or of manufacturing simple apparatus of his own design so that all of the class may perform the same experiment at the same time. To have the whole class working on the same experiment is undoubtedly more efficient educationally as well as more advantageous for student and instructor, as it permits a closer tie between classwork and laboratory.

In eight years of secondary school teaching, I have found it better to purchase only the essential items that cannot be manufactured by myself or by the physics or shop students. The more successful of my colleagues in other schools where funds are limited have found the same thing to be true. I have a list of 66 items which may be prepared in the aforementioned manner or which may be secured gratis from various agencies. Many of these items have originated from parts of old automobiles, radios, phonographs, power transmission equipment, cameras, plumbing fixtures and washing machines. Others have been made in the school shops from wood or metal and ordinary laboratory raw materials. One extremely important source of instructional material is the obsolete equipment of the United States Army and Navy.[1] From this source, I have secured, free of charge, such items as magnetos, altigraphs, anemometers, generators, radio transmitters and receivers, and electrical meters.

Many pieces of apparatus such as specific gravity specimens, force boards or tables, Whiting's apparatus for measuring *g*, vernier models, optical benches, sonometers, and tensile

[1] For specific directions concerning the procedure for securing obsolete Army and Navy materials for accredited public schools, write to the following agencies: War Department, Office of Chief of Ordnance, Washington, D. C.; Chief of Material Division, Air Corps, Wright Field, Dayton, O.; Navy Department, Bureau of Aeronautics, Washington, D. C.

strength apparatus can be constructed in the school shop. Obviously, it is a matter of false economy for a person who has the requisite training required for teaching to devote a large amount of time and energy to the manufacture of apparatus. Most of this should be done by students as shop projects.

Another way to meet the problem of obtaining adequate equipment is to capitalize on the tendency of school boards not to mind a high initial investment if it is known that the yearly cost per pupil will be small. Therefore, it is advantageous to maintain an accurate inventory from which the yearly cost per student for equipment may be figured. If the apparatus is properly cared for, this figure is surprisingly small. When such data are presented with the yearly order, the budget is more apt to be approved in full. This practice also encourages the proper care of apparatus by all of the members of the department and increases its life correspondingly.

The second problem concerns relatively recent reductions in time allotted for laboratory courses. Formerly, most schools were on a 45-minute schedule and laboratory courses were allowed two periods twice weekly. Recently, many schools have changed to the hour period, part of which is used for supervised study. Although this arrangement has proved to be advantageous for other academic courses, it is decidedly less desirable for the science courses. The periods for laboratory are cut from 90 to 60 minutes in length; for a student to draw out apparatus, set it up, and conduct an experiment intelligently in so short a time is exceedingly difficult.

A second reduction in class time has occurred in those schools that have inaugurated an activity program. One hour each day is devoted to extracurricular work and regular attendance at classes is not required during this hour. The class time thus is reduced one period each week —a reduction of 20 percent in the total instructional time. A third cut in time is arising with the trend toward reducing the amount of required homework; in some schools there is the tendency to eliminate homework.

Incidentally, it should be noted that in the extreme case of reduced class time, the entire period devoted to the study of physics in the secondary school in one whole week is but one hour longer than the time spent in a single college laboratory section in one day. I wonder if the secondary teacher should be too severely criticized for the results he obtains under these circumstances.

Our primary duty as physics teachers is to adapt the physics program to that of the school so it will be as effective as possible. We are not employed to formulate administrative policies or to criticize them publicly. Therefore, to cope with the problems created by these new reductions in time we have but one road open; we must organize our work very efficiently. I find it necessary, for the sake of efficiency, to relate very closely the classroom and the laboratory work. This involves preparing students as well as possible during the lecture hour for efficient work in the laboratory the next day. The laboratory apparatus must be so designed that a minimum of time is required to assemble it; and the experimental procedure must be quite clearly defined.

A third imposing problem is that concerned with the personnel of the classes we are required to teach. In many schools there are no prerequisites for taking physics other than that the student have junior or senior standing. As a result, all types of students enrol in physics classes. In a single class, one may have a purposeful, intelligent student, well prepared in mathematics, working with a student who has not had even beginning algebra. The variation in ability, preparation, and purpose in a single class is surprisingly large. Obviously, it is exceedingly difficult to present a course that will be suitable for the future engineer, and at the same time worth while to, and not entirely beyond the grasp of, the less able individual.

For the university instructor, the solution to this problem might appear simple: "Set up definite prerequisites and flunk all of those who cannot make the grade." But, the secondary school solution is not so simple. The compulsory education laws of the various states require that young people attend school. In that law there is an implied obligation for schools to do the best they can for all of the students who enrol, and not to favor a program for the benefit of the estimated 5 percent who may continue the study of physics or related sciences in the universities and colleges.

In the larger schools it is possible to sectionalize the students according to their ability,

preparation, and purpose. The smaller schools cannot afford to offer this advantage. As a result, the physics enrolment goes down when the course is made too rigorous, and a change is made to a more popular teacher. If the standards drop so far that the university rating falls, it becomes necessary to change again to a more rigorous teacher.

A movement is under way which may serve to remove the secondary school physics teacher from his precarious position "between the devil and the deep blue sea." This scheme proposes:

1. To offer physics and chemistry to those students who are able and who are prepared mathematically for rigorous treatments of the subjects.
2. To offer to other students, who desire a general knowledge of the physical sciences, a general course consisting of a fusion of physics, chemistry, geology, meteorology and astronomy.

Such a plan would leave the technical courses free for intensive work with able, well-prepared students, and would provide the general students with a course better adapted to their needs. The northern division of the University of California has encouraged this plan by recognizing the general course as a third or fourth year laboratory science for university entrance. Several secondary school heads of departments who have installed the physical science course have indicated, however, that their schools will not recommend a student for university entrance as a science major unless he has taken the conventional physics or chemistry course. A number of university professors of physics and chemistry whom I have consulted have agreed that the plan is a good one under the circumstances which have just been mentioned.[2]

A fourth secondary school problem relates to the teaching personnel. It resolves itself into the following parts:

1. The physics teacher usually is not trained specifically in the universities and colleges for secondary school teaching; he is usually trained as a research physicist and has had too little opportunity to gain experience of a definite, practical nature which might be applied in the teaching field.
2. As a general rule the best physics students do not enter secondary school teaching as a career, although the remuneration in the educational field is often greater than in the technical fields. This is doubtless caused partly by the fact that many college science departments take the attitude that to enter secondary school teaching is to indicate inability to pursue the regular physics course to the traditional end. The college science departments will not turn out many successful secondary school teachers as long as they have this attitude.
3. The instructor in the secondary school is often required to teach a great variety of subjects. Frequently these subjects are not related to his preparation.
4. It is not unusual for secondary school teachers to go to seed on the job because they are out of contact with other physicists and fail to keep up with progress in the science.

The remedies for these four problems would seem to involve:

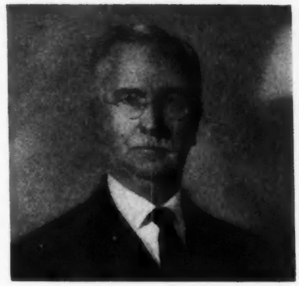
1. The recognition by university and college physics departments of the fact that some students, perhaps the majority, will enter the secondary school teaching field; and that their preparation should be specifically designed to fill that need.
2. The adoption by secondary schools of salary schedules adequate to attract the best students into the teaching field.
3. More care on the part of school administrators to assign only properly prepared teachers to physics courses.
4. The formulation of requirements for the improvement of teachers during service through attendance at summer schools and trade schools.

In summary, the problems involved in teaching secondary school physics as outlined in this paper are:—lack of proper equipment; shortening of class time; lack of mathematical preparation on the part of some of the students taking physics; mixing of good and poor students; and teaching personnel difficulties.

Our efforts toward solving these difficulties are:—manufacture and adaptation of equipment of our own design; more efficient class organization; sectionalizing classes according to ability and purpose, and offering more profitable courses for the nontechnical student; providing suitable training for secondary school science teachers, attractive salary schedules, and means for improvement during teaching service.

[2] Three Pasadena Junior College instructors, Eckels, Shaver and Howard, have made an outstanding contribution to this plan in their book, *Our Physical World* (Sanborn, 1938).

Alexander Wilmer Duff



Recipient of the 1938 Award for Notable Contributions to the Teaching of Physics

Address by Professor D. L. Webster

I HAVE the honor to report that the Committee on Awards for Notable Contributions to the Teaching of Physics recommends unanimously that the award for this year be given to Alexander Wilmer Duff, Emeritus Professor of Physics at Worcester Polytechnic Institute.

Professor Duff's work as editor and co-author of a great textbook of physics, of which we all are reminded immediately by the mention of his name, would alone make him worthy of the award; but it is only one of his notable contributions to the teaching of physics. To enumerate the others, we shall briefly review his life as a teacher.

Professor Duff was born in St. John, New Brunswick, on May 23, 1864. He entered the University of New Brunswick in 1881, graduating as Bachelor of Arts in 1884. Then, he took a competitive examination given by the University of London simultaneously at points scattered over the whole British Empire, and stood first in that world-wide competition. With a scholarship thus won, he passed the other examinations of that university and received a second degree of Bachelor of Arts in 1887. At the University of Edinburgh he became a Master of Arts in 1888, with First-Class Honors in Mathematics and Mathematical Physics, and also Bachelor of Science in 1893 and Doctor of Science in 1901. The University of New Brunswick honored him with the degree of Doctor of Laws in 1920.

While we are concerned here especially with his contributions to teaching, it is of interest to note that Professor Duff's activities have also included research work in various fields, notably viscosity, acoustics, tidal phenomena, and cathode rays. During the World War a research was carried out on the trajectories of bombs, in which about ten men, of whom I had the good fortune to be one, served under Professor Duff's leadership. As one of the younger members of that group, I could speak at length of his friendly spirit, his tolerance and kindliness to us all, and the practical wisdom that made it a pleasure to carry out his plans.

In teaching, his first appointment as professor of physics was at the University of Madras, India, in 1889. In the next year he returned to the University of New Brunswick; in 1893 he went to Purdue University; and, in 1899, to Worcester Polytechnic Institute. He became Emeritus Professor there in 1936.

Among Professor Duff's many contributions to teaching, through textbook writing, were his *Elementary Experimental Mechanics* in 1905; his *Physical Measurements* (with A. W. Ewell) in 1910; his *College Physics* in 1925; and his *Elements of Physics* (with H. T. Weed) in 1928.

The most notable of all these contributions, however, was one extending over more than thirty years, the one entitled *A Textbook of Physics*, of which the first edition appeared in 1908 and the eighth, last year. During these thirty years, 130,000 copies have been sold, and the book has been used extensively beyond the boundaries of our country, especially in Great Britain. While Professor Duff's own contributions as author were in mechanics and sound, his work as editor was very important in all

parts of every edition. His publisher, Blakiston's, writes as follows:

> In 1908, when this book was first published, Professor Duff had six collaborators. From the very beginning he has not only contributed a section to the text but has comprehensively edited the contributions of all the collaborators. It was necessary in Duff's judgment to present a book that was homogeneous. His task as editor included interrelating the various parts, deleting, filling in gaps, clearing ambiguities, and modifying over-statements, fads and fancies. He took this entire task seriously in the first edition and has held to this position throughout all eight editions. As you know, the collaborators today are not the same as those who contributed to the first edition; nonetheless, Duff has succeeded in continuing to coordinate the contributions satisfactorily.

During a part of the thirty years in which he was working on his *Textbook of Physics*, Professor Duff found time for another very notable contribution to teaching, as chairman of the Educational Committee of the American Physical Society and author of its first report. This report was issued in 1922 and entitled "The Teaching of Physics with Especial Reference to the Teaching of Physics to Students of Engineering." Although it was concise, for such a large subject, with only 55 pages, it laid the foundation for work in all phases of physics teaching, from the most immediately practical to the guiding principles of our ambitions for the evolution of our profession.

Now, sixteen years later, it may be difficult for younger members of this Association to visualize the physics teaching of 1922. Forty or fifty years before that, physics had been taught in this country but the science had not been made a subject for research. When research began, it was treated by university administrations as a hobby that took a teacher's attention away from his work. Only by a long struggle did the American Physical Society succeed in getting creative work established on a status of proper professional dignity, in which it could grow normally. In 1922, research had won its place but was still on guard against a counter attack. So it took great courage, as well as ability as a teacher and educational philosopher, for Professor Duff to lead this committee and to write this guidebook to the future of the teaching of physics. We here, members of the American Association of Physics Teachers, are met today to honor one of our great pioneers.

Mr. President, it is both a pleasure and an honor to recommend, in the name of the Committee, the Award for Notable Contributions to the Teaching of Physics to Professor Duff.

Presentation of Award by President Richtmyer

Professor Duff, it is my pleasure and privilege, upon the recommendation of and for the reasons set forth by the Committee, to award to you on behalf of the American Association of Physics Teachers the Oersted medal for notable contributions to the teaching of physics. In token of this award, I hand you this medal and the accompanying certificate as tokens of our esteem, of our indebtedness to you for many contributions to our profession and for the inspiration which your work has been to us these many years. We shall look forward eagerly to your continued inspiration and leadership.

Acceptance of Award by Professor Duff

I feel very highly honored by the presentation to me of this medal and testimonial for what the committee has deemed a contribution of some value to the teaching of physics. In fact, I feel as highly honored as I would if I could feel that I deserve the honor. I think I must attribute the generosity of your references to my services in part to the spirit of kindliness and good will to all men that should characterize this season of the year, and in part also to the recognition that approval of well-intended efforts of any kind, however imperfect the performance may be, supplies one of the strongest incentives to improvement in any field. Possibly the im-

portance attached to the existence of satisfactory textbooks, which you show by this presentation, may induce others to prepare better ones.

That there is room for improvement in textbooks, as in all other fields of human endeavor, there can be no doubt. Like many other things in the world about us, the work of the textbook writer is becoming ever more and more complex as time goes on. Our knowledge of the physical universe is increasing at a highly accelerated pace, perhaps more rapidly in the field cultivated by the physicist than in any other. How are we to grapple in our textbooks with this ever increasing mass of knowledge? If, as someone has humorously said, highly specialized research consists in learning more and more of less and less, the work of the textbook writer consists in telling less and less of more and more. The result is the terse staccato style of our present books, in contrast with the more leisurely exposition and greater literary grace that characterized some of the English books of half a century ago.

Like other textbook writers, I have sometimes been asked what could be done to improve the quality of textbooks. This is too large a subject to be discussed in detail in the short time at my disposal, but there is one aspect of it that I may mention briefly. You will all agree that to leave removable stumbling blocks of any kind in the path of the learner is very undesirable. That we do have many such stumbling blocks is known to every textbook writer, though whether they are removable is a different question. Consider, for example, the erratic terminology that has grown up and been perpetuated in this, the oldest of the sciences. Without attempting to survey the whole of physics from this point of view, I may mention two or three illustrations of what I mean. We no sooner tell our students that certain things are called "electromotive forces" than we proceed to add that they are not forces in the sense in which the term is used in mechanics, but are called so because someone made a mistake about the whole thing a long time ago. Would it not be better, then, in the interest of clear thinking, as well as effective teaching, to replace the term by something in keeping with such terms as resistance, conductance, impedance, and so on—say, for example, *electromotance?* Another example of faulty terminology is "dielectric constant," which is not one of the physical constants so admirably tabulated by Professor Birge, nor even something that is invariable for a single body or substance. Would it not be much more logical to rechristen it, say, *dielectrance?* Then there is "susceptibility," of which there are two kinds, one for electricity and one for magnetism, so that it has to be associated with an adjective to reënforce its six syllables. The word itself is more suggestive of a romantic novel than of the field of science. Could we not replace "electric susceptibility" and "magnetic susceptibility" by *susceptance* and *magnetance?* As another example, why should we go on using the lengthy word, "permeability," when we could halve the number of syllables and be more consistent in our terminology by reducing it to *permeance?* Many other examples might be mentioned of the same defect in terminology, and, as well, of discordance in the use of both terminology and notation. A good deal of time is wasted by anyone who is consulting reference books and research papers in first discovering and then keeping in mind the particular terminology and notation used.

Now I am not suggesting that this Association or any single association could introduce order or system in such matters; but I have often wondered whether, if some one organization had the courage to take leadership in these things, something like agreement could not be reached, with marked advantage both to teaching and to research. It seems to me that we have allowed ourselves to be outstripped in this matter of consistent terminology by some other sciences in which the subject matter does not in itself permit of such precision as we attain in physics.

But these are subjects for further consideration on some other occasion, and I will close by thanking you again for the very great honor you have done me by presenting me this mark of your approval of whatever I have been able to do in the way of assisting the teaching of physics in our colleges and universities.

Experiments on the Absolute Determination of Electrical Units

R. D. RICHTMYER AND W. W. HANSEN
Department of Physics, Stanford University, Stanford, California

IN THESE experiments, which are suitable for a course in electrical measurements, the student determines the values in absolute electromagnetic units of a current, a mutual inductance, and a resistance by measurements of mass, length and time only. Since it is in principle possible to determine the value in emu of any other electrical quantity in terms of the foregoing ones, the whole electromagnetic system of units may be considered established.

An experiment in which the value of c is determined will be described also. The only *electrical* standards used in this experiment are those of resistance and self-inductance, calibrated in practical units. Since practical units are derived from the electromagnetic system, these standards are in principle derivable directly from the preceding experiments; so the whole electrostatic system may also be considered established.

Experimental errors are not more than about 0.25 percent in any case.

MEASUREMENT OF CURRENT

The object of this experiment is to make simple absolute measurements of current. Moreover, the aim is to achieve sufficient accuracy so that the experiment may be used in practice, as well as in principle, to calibrate ammeters or other secondary standards of current.

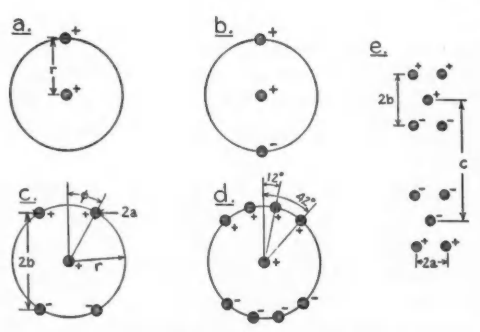


FIG. 1. Sectional views of various arrangements of parallel wires that might be used in current weighers. The + and − signs indicate the direction of the current. Type a is impractical. Type b was used by Warburton, with the upper and lower wires attached to the balance, and the center wire fixed. Type c is used in modified form in apparatus here described, the central wire being attached to the balance. Type d is also described. Type e is the arrangement finally employed.

As is well known, absolute measurements of current are often made by using a "current weigher," which measures the electromagnetic force between two current-carrying wires. A device of this type suitable for use by students has been described by Warburton.[1] The present apparatus is, broadly speaking, similar to Warburton's, but has a few important modifications which we feel are improvements.

To aid in understanding these modifications, consider Fig. 1, which shows various arrangements of conductors that might be used for simple current weighers. For example, Fig. 1(a) shows 2 parallel wires both carrying a current i in the same direction; they will be attracted with a force of $2i^2/r$ dyne/unit length, and one would measure this force and r, and so find i. Such an arrangement is, of course, hardly practical because the distance r must be measured accurately, which is difficult because one of the wires must be fastened to the balance, thus making it hard to measure its exact position at the time the force is measured. Moreover, because the electromagnetic force is not independent of r, the balance will act as if it had a different (increased) restoring force when the current is on; and this would cause difficulties in the weighing.

Both these troubles are largely avoided by the arrangement used by Warburton (Fig. 1(b)). Here the force per unit length is $4i^2/r$, and r, being fixed, is capable of precise measurement. Moreover, if the two wires which are attached to the balance, and so are movable, are displaced slightly in the vertical direction, the force does not change much. To be exact, if the displacement is x, the force per unit length is $(4i^2/r)(1+(x/r)^2\cdots)$. Although this arrangement is good, improvement may be desirable, especially if one aims at greater precision. Thus if r is made 1 cm, as in Warburton's instrument, then a displacement x of 0.1 cm gives an error of 1

[1] F. W. Warburton, Am. Phys. Teacher 4, 124 (1936).

percent and this may be serious, though it is apparent that Warburton must have succeeded in keeping x less than 0.1 cm.

This difficulty is largely avoided and various other advantages obtained by the use of the arrangement shown in Fig. 1(c), where 4 wires are used to produce the field in which the central wire moves. Here there is not only symmetry, which eliminates the odd powers of (x/r) in the expression for the force, but also a disposable parameter ϕ, which specifies where the wires are on the circle; and, by proper adjustment of ϕ, the coefficient of the first even power of (x/r) may be made zero. In fact, if ϕ is 30°, the force per unit length is $(4\sqrt{3}i^2/r)(1-(x/r)^4\cdots)$. As a result of the improved uniformity of field obtained with this arrangement, which can be considered as a sort of two-dimensional Helmholtz coil, a centering error x of $0.1r$ now gives an error in force of 0.01 percent, which is negligible.

The actual arrangement we use is adapted from that of Fig. 1(c) and is shown in Fig. 1(e). It has the following advantages in addition to those previously mentioned. First, by employing two systems similar to Fig. 1(b) and using the center wire as the movable one, the force obtained by Warburton is doubled without appreciably increasing the load on the balance. Actually, we use two arrangements like Fig. 1(c), thus multiplying the force by another factor $\sqrt{3}$. Second, the important distance r is now a dimension of the *fixed* system of coils, and this system naturally can be made more rugged and precise than might be the case if it had to be designed for suspension from an analytic balance.

Parenthetically, we remark that in case a still more uniform field and a higher force are desired, the best arrangement for 8 stationary wires and 1 moving wire is that shown in Fig. 1(d). The force per unit length for this arrangement is $(13.15\, i^2/r)(1+0.62(x/r)^6\cdots)$.

As to the theory of the device, only two additional remarks are needed. First, since the angle ϕ in Fig. 1(e) is not easily measurable, whereas the lengths $2a$ and $2b$ are, it is better to specify the configuration of the wires by means of a and b rather than r and ϕ. Second, there is a slight interaction, not hitherto mentioned, between the lower 4 stationary wires and the upper movable wire and, likewise, between the upper stationary and the lower movable wires. Taking these two facts into account, we find for $(m_2-m_1)g$, the change in apparent weight of the movable loop when the current through the fixed wires is reversed,

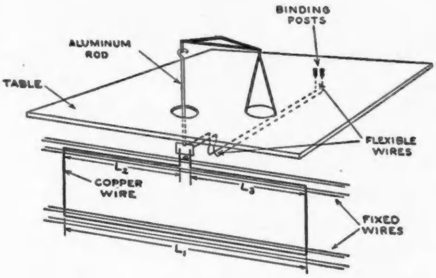


FIG. 2. Diagram showing the current weigher.

$$(m_2-m_1)g=\frac{16i^2b}{b^2+a^2}(L_1+L_2+L_3)\left(1+\frac{a^2+b^2}{c^2}\right), \quad (1)$$

where the L's are various lengths relating to the loop as shown in Fig. 2. The last bracket is the correction for the force on the upper movable wire due to the lower stationary wires, etc., and, strictly speaking, is an approximation valid only when $1\gg(a^2+b^2)/c^2$. Ordinarily this condition is well fulfilled; in our apparatus this correction is about 1 percent.

It should be pointed out to the student that, as is shown by Eq. (1), the absolute dimensions of the apparatus do not matter; only the relative dimensions are important. In precision determinations of the abampere the various ratios of lengths are usually measured electrically, but this is not easy with the present apparatus.

The actual form of apparatus used is quite similar to that of Warburton, except for the more complex arrangement of wires, and is illustrated in Fig. 2. The fixed wires are bare No. 14 copper wires and are stretched on a frame (not shown) whose position can be adjusted by suitable screws. The wires are fixed relative to one another by passing them through suitably placed holes in two pieces of Bakelite placed near the ends of the wires. The needed dimensions are easily found with the aid of vernier calipers and a meter stick. These dimensions are such that m_2-m_1 is about 1 gm when i is 15 amp. Since there is no difficulty in measuring a force of this magnitude, the student can *calibrate* a medium quality d.c. ammeter with this apparatus.

Measurement of Resistance

In this experiment a resistance is determined in terms of length and time, the length being that associated with a mutual inductance and the time being connected with a frequency.

The principles involved are illustrated in Fig. 3. Here M is a mutual inductance whose value in centimeters is calculable from its dimensions and R is the resistance to be determined. Also the frequency ω of the alternator in radians per second can be determined. To find R, one makes adjustments until the potential difference across R is equal in magnitude to that across the secondary of M, when we have

$$R = M\omega.$$

Now we have to show that this equality can be determined with sufficient precision and also that the tacit assumption of a pure sine wave current is realizable in practice. As to the first, we have used two different methods, one of which involves an ordinary electrometer; the other, two vacuum tubes.

If the electrometer, shown connected in Fig. 3, is symmetrical, a zero reading plainly implies equality of the rms values of the two voltages applied. Effects of asymmetry are small and are canceled out by reversing the connections. Moreover, with voltages of the order of 100 v across R and M, a crude electrometer is sufficiently sensitive to indicate a difference of 0.1 percent between V_1 and V_2. Also, it is plain that the capacitance current drawn by the electrometer is negligible. Although we find the electrometer satisfactory, it must be admitted that applying 100 v across R, which is of the order of 100 ohms, produces a power dissipation problem. This might be remedied by substituting a fine electrometer suspension for the galvanometer ribbon we used.

An alternative plan is to develop an entirely different balance indicator, such as the one we now describe. It consists essentially of two '37 vacuum tubes, arranged as shown in Fig. 4. The tubes operate as detectors, the microammeter G indicating the difference of the detected signals. By slightly adjusting the resistance pairs R_1, R_2, and R_3, R_4, the sensitivities of the two detectors may be equalized, and also their plate currents

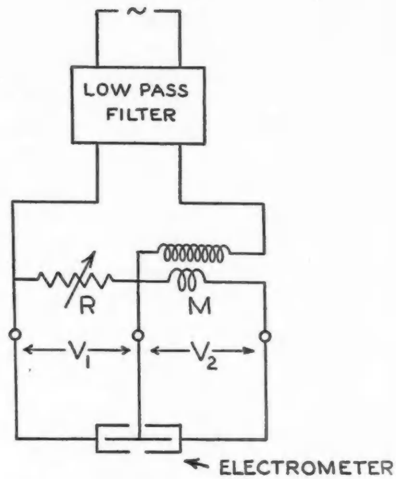


Fig. 3. Apparatus used for the absolute determination of a resistance R in terms of the calculable mutual inductance M and the frequency of the alternator. An electrometer is shown as the balance indicator.

for zero signal. In adjusting for equal sensitivities use is made of voltages V_1 and V_2 from two equal resistors in series. In use, further symmetry is introduced by employing two reversing switches (not shown). One interchanges the two grids relative to the two voltages V_1 and V_2. The other interchanges the two ends of the secondary of M. For one position of this switch V_1 leads V_2 by one quarter cycle; for the other, the reverse is true.

This balance indicator has been found very satisfactory and rather more sensitive than the electrometer we used. Thus with V_1 and V_2 about 10 v, a difference of 0.1 percent is easily detected.

Now we must consider the disturbing effects of harmonics and their elimination, for it is plain that the presence of harmonics will cause errors. Quantitatively, one can show that if the current input is

$$i = \sum_1^\infty a_n \sin(n\omega t + \beta_n)$$

and the balance indicator is a square-law instrument of some sort, then

$$R = M\omega\left(1 + \sum_1^\infty (n^2 - 1)(a_n/a_1)^2\right).$$

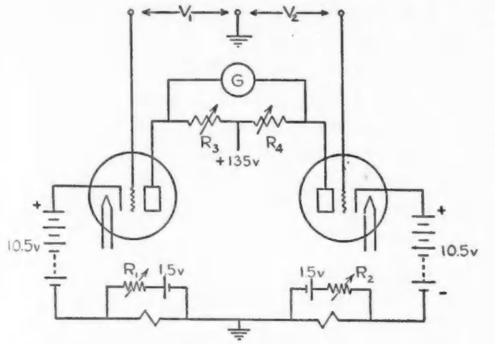


FIG. 4. An instrument that may be substituted for the electrometer shown in Fig. 3. Resistances R_1, R_2 are about 50 ohms; R_3, R_4 about 100 ohms.

This error may be serious, and, in fact, is the principal objection which has been raised to the use for precision work of methods similar to that here described. For example, the first important harmonic will almost always be the third, and 10 percent of the third harmonic will give an 8 percent error.

Ordinarily, a 60-cycle power circuit will not have anything like this harmonic content; in fact, the errors arising from harmonics in this case probably will always be negligible. Nevertheless, a search should always be made for harmonics. When we did this, using an oscillograph as an indicator and with a tunable resonant circuit to augment the harmonic under investigation, we discovered harmonic content sufficient to cause about 5 percent error. This rather impure wave form resulted from our use of a small inductor alternator as a source of power.

The unwanted harmonics were easily eliminated by means of a low-pass filter. This was designed to cut off between the first and third harmonics, as one can be sure there will be no second harmonic. Of course, no iron is used in the coils. The only point to be watched in designing such a filter is that the impedances of the filter and the load should match reasonably well.[2]

In the actual apparatus, the mutual inductance is made similar to, but somewhat larger than, those commonly used for calibrating ballistic galvanometers, this form being chosen because the computations are simple enough for students to understand. The primary (upper coil in Fig. 3) consists of about 1000 turns of No. 20 wire wound in a single layer on a 3-ft length of 6-in. Bakelite tube. The exact number of turns N_1 is known, and the student can measure the diameter D_1 and length L_1. The secondary is a multilayer coil of about 2500 turns (N_2) of fine wire wound about the middle of the primary and not extending more than 1 in. either side of the middle. Several secondaries may be provided to give several different values of M. With the proportions just given, M may be computed with sufficient accuracy by means of the equation

$$M=\frac{N_1N_2}{L_1}(\pi D_1)^2\frac{1}{[1+(D_1/L_1)^2]^{\frac{1}{2}}}.$$

For the dimensions described and a frequency of about 500 cycle/sec, $M\omega$ is about 100 ohms. Thus, even if the frequency is reduced to 60 cycle/sec, the resistance measured is still of convenient size.

The resistance R calls for some comment, because the required power dissipation may be large. This is especially true if an insensitive electrometer is used as a balance indicator, or if M is small. For example, when working with an electrometer, we have used as much as 100 v across R and this corresponds to a power dissipation of about 100 w. We made a simple resistor that would dissipate this power without appreciable resistance change by winding a 1-in. brass tube about 30 in. long with sufficient No. 30 manganin wire to give 100 ohms. The winding was done in the Ayrton-Perry manner. When the tube is cooled internally by a stream of water this resistor will dissipate about 400 w without appreciable change of resistance. Since the resistor as described is not adjustable, it is best to construct it with approximately the correct resistance and achieve the final balance by adjusting a small series or a large parallel auxiliary resistor.

As previously mentioned, a generator of about 500 cycle/sec was used as a source of power. The frequency was determined by counting and timing revolutions of the alternator. If easily available, a frequency of this magnitude or perhaps higher is useful, as the larger ω is, the

[2] For a brief and useful discussion of filter design, see F. E. Terman, *Measurements in Radio Engineering* (McGraw-Hill, 1935), p. 349 ff.

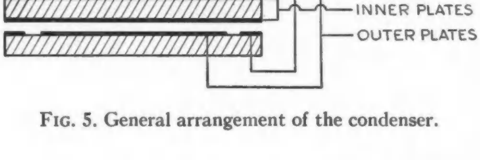


FIG. 5. General arrangement of the condenser.

larger R will be, and so the lower the power for given voltage. However, 60-cycle current from the mains is quite satisfactory, especially if one uses the vacuum tube type of balance indicator. If this source is used, its frequency may be determined by comparing an electrical and a mechanical clock.

With the apparatus described, it is not difficult to make absolute determinations of resistances of the order of 100 ohms with an accuracy of 0.25 percent or better. Thus the students can make resistance units that are just as accurate as the purchased resistance boxes ordinarily furnished to them.

RATIO OF UNITS

Our experiment for the measurement of the ratio of electromagnetic to electrostatic units is the standard type in which one constructs a condenser whose capacitance in esu can be calculated, measures this capacitance in emu, and so finds the ratio c. For this, one would like to use only those electrical standards established in the experiments previously described. However, since the student has been taught, in another part of the course, how to compare resistances and how to compare self and mutual inductances, we permit him to use any standards of resistance and inductance whose values are known in practical, and so in electromagnetic, units.

The main piece of apparatus is, of course, the condenser and its design is subject to the conflicting requirements that both the capacitance and the distance of separation should be large enough to be easily measurable. Our solution of this problem was to make a parallel plate condenser of rather large area ($\sim$4000 cm^2), using silvered plate glass as a material because of its flatness. The spacing is about 1.5 mm, thus giving a capacitance of about 0.002 μf which is easily measured.

To make the condenser, we took 3 pieces of good plate glass, about 2×1 ft, and silvered them by the ordinary chemical deposition process. One piece was silvered on both sides. Each of the others was silvered on one side; then a stylus was used to remove the silver from a line bounding a rectangle which comes within 1 in. of the edge of the glass. The inner rectangle serves as a condenser plate; the 1-in. border, as a guard ring. The dimensions of these scratched rectangles were measured and then the condenser was assembled as shown in Fig. 5. The spacers which hold the plates apart were made from microscope slides (not cover glasses). One slide was broken into 9 pieces; 8 of these were used to space the two bottom plates, and the remaining piece was kept for the students to measure with micrometers. Similar spacers were used for the upper plates. Six of the 8 spacers were in each case placed around the edge, between the guard ring and the inner plate, leaving only 2 in the condenser proper. The dielectric effect of these spacers alters the capacitance of the condenser by less than 0.1 percent and is therefore ignored. Though the thickness of these spacers is small, one can, with care, measure the thickness to about 0.25 percent. A more accurate measurement doubtless could be made by piling the 8 spacers up and measuring them all at once.

The a.c. bridge used to measure the capacitance in emu is shown in Fig. 6. Since the resistor R_4 is in parallel with C, the balance is independent of

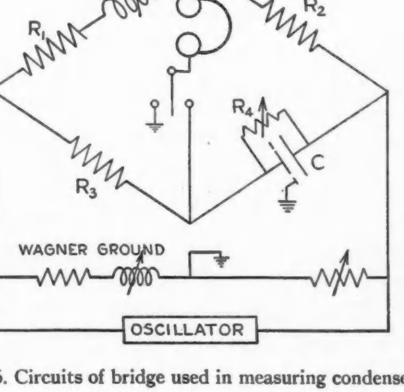


FIG. 6. Circuits of bridge used in measuring condenser.

frequency. Conditions of balance are

$$R_1R_4=R_2R_3=L/C,$$

and C is computed from $C=L/R_2R_3$. The approximate values used were R_2, $R_3\sim 7000$ ohms, $R_1\sim 200$ ohms, $R_4\sim 200{,}000$ ohms, $L\sim 0.1$ h, and a frequency of 1000 cycle/sec.

In practice, no difficulty is experienced in measuring C to well within the $\frac{1}{4}$-percent limit set by the difficulty of measuring the spacers. Since c depends on $\sqrt{C}$, the ratio of the units is obtained with slightly greater accuracy.

A Displacement Polarimeter

Newton Underwood
Department of Physics, Vanderbilt University, Nashville, Tennessee

SENARMONT[1] devised a displacement polarimeter in which the light in one-half of the field is given a varying degree of rotation by a right-handed quartz wedge and in the other half by a left-handed quartz wedge. Consequently, for a given position of the analyzer two dark bands appear, one in each half of the field. When the analyzer is rotated, the two bands move in opposite directions. The position of coincidence is chosen as the zero position. Senarmont does not give data showing the accuracy of the device.

The present instrument is based on a rather curious phenomenon which may be seen when uniaxial crystals are examined in polarized light. The optical system for observing this consisted of a polarizer, a quarter-wave plate, the crystal specimen, and an analyzer.

First the Nicols are set for extinction, then the quarter-wave plate is inserted with its axis parallel to that of the polarizer, and finally the uniaxial crystal is placed in position. A quartz crystal cut so that its faces are perpendicular to the optical axis is perhaps the easiest to use. On looking into the analyzer, one sees the expected ring system. But a slight rotation of the polarizer causes a deformation of the rings. This deformation is shown by the accompanying photographs. Fig. 1 shows a portion of the ring system as it appears when there is a slight angle between the analyzer and the polarizer; notice the Y type juncture at the bottom of the field and the lessening deformation toward the top. Fig. 2 shows the same field with the analyzer rotated 2.5°; the forked juncture is now at the 4th ring from the bottom (actually the 9th from the center of the ring system). Fig. 3 shows the same field when the analyzer is rotated 2.5° further; the Y juncture has gone out of the picture at the top and the lower 3 rings form good circles.

Suppose that we start with the nth ring in the left-hand half of the field in alignment with the nth ring in the right-hand half of the field. Then

[1] M. H. de Senarmont, Ann. Chimie et de Phys. **28**, 279 (1850).

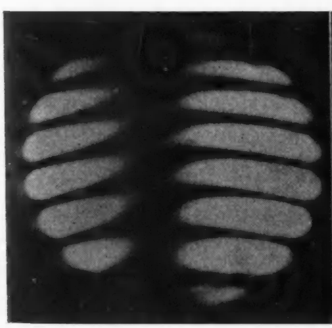


Fig. 1.

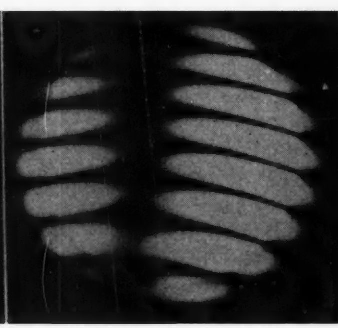


Fig. 2.

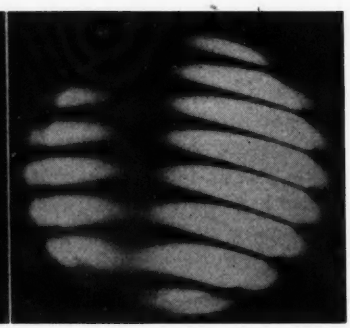


Fig. 3.

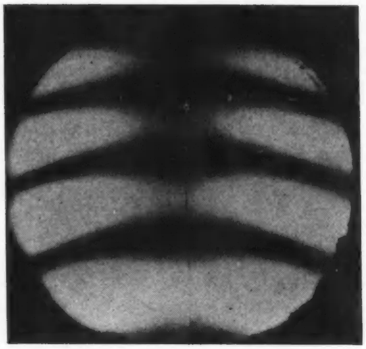


FIG. 4.

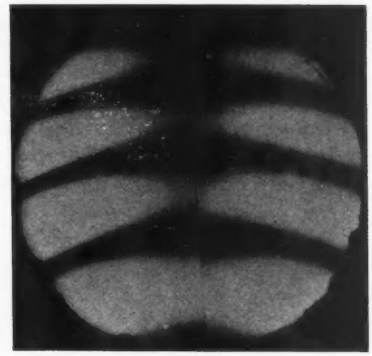


FIG. 5.

it is evident that a small rotation will cause the nth ring on one side to line up with the $n+1$st ring on the other side. It was first thought that equipping the eyepiece with cross hairs and observing the motion of the Y juncture into position behind them would give a sensitive test for the angular adjustment and afford a basis for a displacement polarimeter. Unfortunately, the illumination becomes poor and the detail hazy as one observes farther out into the ring system. Upon moving in toward the center of the ring system, the illumination and clearness improve, but the angular displacement necessary to produce the change increases. These factors almost compensate for one another, so that the reliability of setting is about the same when working around the 3rd ring as it is when working near the 15th ring. Since the illumination is better nearer the center, less eyestrain is involved. The reproducibility of settings is within 1°. The main difficulty with the arrangement is caused by the lack of clarity in the transition zone.

It has been found possible to increase the clarity greatly by modifying this arrangement so that the quarter-wave plate covers only one-half of the field. Under these circumstances, the character of the phenomenon is changed. The two halves of the field are now separated by a clear and sharp line of demarcation. The rings in the two halves of the field shift in relative position from out-of-stepness to juncture, and finally to out-of-stepness on the other side as the analyzer is rotated. Note that the nth ring never joins the $n+1$st ring as was previously the case. Fig. 4 shows the field of view when the rings are lined up. Fig. 5 shows the lack of alignment caused by a rotation of 2°.

If the angular position at which the rings are lined up is chosen as the zero position, the insertion of an optically active specimen between the polarizer and the wave plate causes the rings to be thrown out of line. They can be brought back into juncture by rotating either the polarizer or the analyzer so as to compensate for the rotation produced by the specimen, and thus its rotation can be measured.

Trial has shown that it makes little, if any, difference what type of wave plate is used. This is a fortunate circumstance; otherwise, changing to different wave-lengths would necessitate a series of quarter-wave plates, one for each color. Pfund[2] has pointed out that Cellophane is doubly refracting, its axis being in the direction of the grain, and that it can be used to make a half-shade device.

A piece of Cellophane cut with its edge parallel to the grain makes an excellent wave plate for the polarimeter. Polaroid is quite satisfactory for use in place of Nicol prisms. The quartz may be replaced by a piece of strained glass or plastic which gives a fringe system. However, quartz is much the best to use. The present polarimeter (Fig. 6) is constructed with Polaroid, quartz, and Cellophane.

The quartz is tipped so that a convenient portion of the ring system is in the field of view. The Cellophane half-field is mounted so that it can be brought into focus by the eyepiece lens

[2] A. H. Pfund, J. Opt. Soc. Am. **26**, 453 (1936).

TABLE I (a). *Good illumination.*

Lippich Polarimeter		Displacement Polarimeter	
Zero position	Angle	Zero position	Angle
359.85°	3.56°	0° 0′	356° 29′
.88	.55	2	25
.88	.53	2	26
.87	.56	1	27
		5	29
Av. 359.87°	3.55°	6	29
3.68°		4	30
		1	29
		1	27
		3	20
		Av. 2.5′	356° 27′
		0.04°	356.45°
		Rot.,	3.59°

TABLE I (b). *Poor illumination.*

Setting	Setting
3.93	356° 29′
.74	12
.70	21
.85	28
.80	14
.88	20
.80	19
.77	21
.70	14
.95	20
.87	20
Av. 3.82°	356° 20′
a.d. 0.07°	a.d. 0.06°

while the eye is focused on the ring system. The lens (focal length about 1 in.) also serves the purpose of providing convergent light through the quartz. The whole assembly of Cellophane, lens, quartz and Polaroid moves with the analyzer circle. If it is desired to keep the division between the two fields in one position, the polarizer can be rotated instead of the analyzer.

In order to check the accuracy of the device, the rotation of a sugar solution was measured first by it, and then by a precision half-shade polarimeter. The angle measured by the displacement polarimeter was 3.59°. The rotation

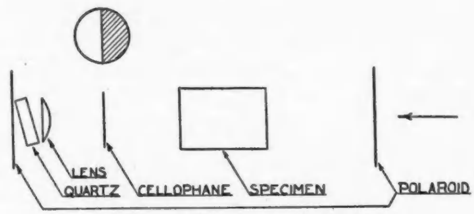


FIG. 6. Schematic drawing of polarimeter.

of the same solution in the same polarimeter tube was found to be 3.68° when measured by the Lippich instrument. The agreement is satisfactory. The extent to which a series of settings will agree among themselves is shown in Table I(a). The average deviation of 84 settings was 2′. If we ignore 7 bad settings out of the 84, the extreme variation is 6′.

The Lippich half-shade polarimeter is a precision instrument and would be difficult to surpass as long as the illumination is good. However, when visual conditions are bad, its accuracy falls off as is indicated by the data in Table I(b), which were taken with poor illumination. The displacement polarimeter yielded the data shown in Table I(b) when the illumination was cut down by the same filters used with the Lippich. These results indicate that under poor conditions of illumination the present polarimeter achieves an accuracy comparable to that of the Lippich operating under the same conditions. It must be pointed out, however, that the displacement polarimeter is quite sensitive to changes in ellipticity, and that slight strains in the end plates of the polarimeter tube which do not cause trouble with the Lippich may introduce serious errors. With good illumination the present device is accurate to about 0.1°.

The author is indebted to Doctor F. G. Slack and Doctor Philip Rudnick for many helpful suggestions and ideas given him during the course of the work.

Forthcoming International Congress for the Unity of Science

The fifth International Congress for the Unity of Science will be held at Harvard University, September 5–10, 1939. The main theme for the meetings will be the logic of science, with interest centered on the relations of the concepts, laws and methods of the various sciences. Particular attention will be given to general problems connected with the logic of the physical sciences, the relations of the sciences to one another, and the relation of the biological sciences and the sociohumanistic studies. Professor P. W. Bridgman is chairman, and Doctor W. V. Quine, secretary of the committee on arrangements at Harvard University. Those who wish to receive later notices of the Congress should communicate with Professor C. W. Morris, University of Chicago.

Phase Relations in an Inductance Demonstrated at Low Frequency

G. E. Feiker and W. B. Wadsworth
Worcester Polytechnic Institute, Worcester, Massachusetts

THE usual laboratory experiment on inductance measurement, by means of a somewhat complicated alternating-current bridge, fails to give the average student an understanding of the action of the inductance as it affects the relations between current and voltage in an a.c. circuit. It is desirable that the phase relations in an inductance be demonstrated in a way easily understood by the student, and that the relations be differentiated from those associated with pure resistance and capacitance.

The difficulty in making clear the current and voltage relations is that the ordinary meters with which the student is familiar cannot be made to act quickly enough to follow the alternations. Of course, wave forms may be shown by the aid of a cathode-ray oscilloscope with complicated sweep circuit; but to understand the action of this device, the student must be familiar with the very things that are to be demonstrated to him. In the apparatus to be described a generator is used whose frequency is so low that ordinary meters, with which the student is in the habit of working, may be employed to trace the alternating voltages and current.

The simple apparatus used to produce the alternating voltage of 0.2 cycle/sec is illustrated in Figs. 1 and 2. An eccentric, attached to the rotating disk, moved a carbon brush along a 5-in. strip of ribbon Nichrome wire in a harmonic motion. Thus the potential of the brush varied sinusoidally from a positive to a negative maximum, with a frequency that depended upon the speed of the disk. Small table galvanometers were connected as shown to read applied voltage and current, and to indicate self-induced voltage. No care was taken to adjust the amplitudes of the meters to show relative values, since only phase relations were to be demonstrated.

FIG. 1. Low frequency alternator of period 5 sec.

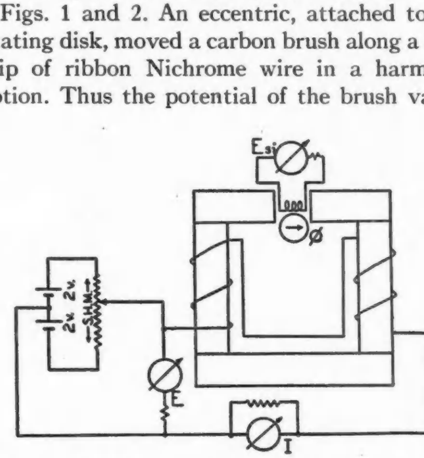


FIG. 2. Circuit of alternator and coil, with meters connected to read applied voltage E, current I, self-induced voltage E_{si}, and flux ϕ.

A large iron-cored reactor was selected for the inductance. The ratio of inductive reactance to resistance ($\omega \cdot L/R = \tan \phi$) was about unity for the coil used, so that the resulting phase angle was 45°. The time constant of the coil—ratio of inductance to resistance—was, therefore, a little less than 1 sec. The pick-up coil for the self-induced voltage, placed in a small air gap in the iron core of the reactor, consisted of a great many turns of fine wire.

The iron served to increase the inductance to a value large enough to give a noticeable phase angle. Since the amplitude of the current was small, about 0.15 amp, and the resulting current-voltage relation was linear, a sine wave of current was obtained.

The motion of the current-indicating galva-

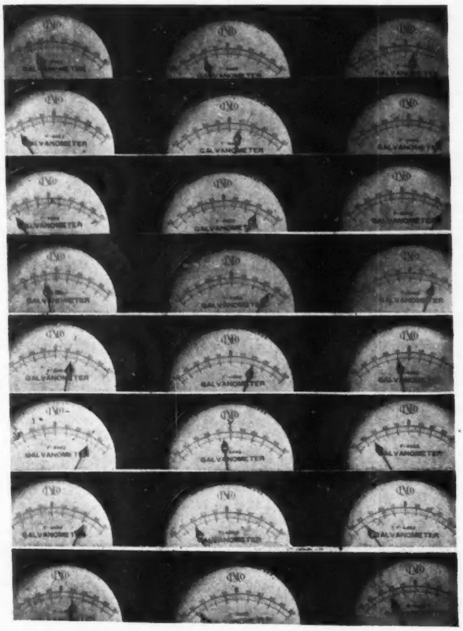


FIG. 3. Galvanometer readings of self-induced voltage E_{si}, current I, and applied voltage E, for eight phases of a cycle. Read from top to bottom.

nometer was found to lag that of the applied voltage meter by about $\frac{1}{8}$ cycle, or 45°, and the sine wave of self-induced voltage was observed to lag the current approximately 90°.

The distinguishing characteristics of the inductance were shown by comparing the relation between current and voltage in the inductive circuit with the relation in a capacitive circuit. With about 100μf of capacitance in place of the inductance, the current meter was observed to lead the voltage meter by a quarter of a cycle. The characteristics of a pure resistance could likewise be shown. By combinations of the three, the meaning of leading and lagging power factors, of power-factor correction, etc., could be easily demonstrated.

The experiment was designed primarily for visual demonstration; but measurements were obtained, by photographic recording, of meter readings at successive phases of the cycle. The scale of a quick-acting d.c. milliammeter, placed near the air gap to give a measure of the flux, was included in the photographs. A magnetic relay, which could be set to any desired phase position, actuated the shutter of the camera.

The photographs of eight consecutive phase positions for one cycle shown in Fig. 3 permit one to trace the general outline of the alternations of current and voltage. The sine waves plotted from the photographed readings are shown in Fig. 4.

It will be observed from this graph that the flux lagged the current by about 30°. With damping, the difference of phase between the mechanical actions of the meters was about 20°. In visual observations of the actions of the meters, the self-induced voltage seemed approximately 90° out of phase with the current, since the relation of the maximum of one curve and the zero-point of another was not easy to ascertain by eye. Actually, the self-induced voltage was 90° out of phase with the flux, as the graph plotted from the photographs indicates.

This relation between current and flux is probably due to two causes: the eddy currents in the iron produce a flux, which lags the flux associated with the primary coil; and the loose coupling of the primary coil and the pick-up coil introduces a phase shift between the flux which threads the pick-up coil and the flux which exists in the large iron core. With the apparatus set up as in this investigation, the flux meter gave an indication of the flux which threaded the pick-up coil; hence there was a 90° relation between the curves of flux and self-induced voltage. If the pick-up coil is to measure accurately the voltage induced by the change of flux in the iron core, it should be wound around the primary coil. The effect of eddy currents in producing a resultant lagging flux in the iron can be eliminated by laminating the iron core. The effect of lagging flux here obtained is interesting in that it shows clearly that induced voltage depends primarily upon rate of change of flux rather than upon the rate of change of primary conduction current in an iron-cored coil. The device could be used to distinguish between the phase shift caused by leakage and that caused by eddy currents, a matter of some importance in the study of the action of a transformer.

The 5-sec period for the alternation was found to be satisfactory for observing the phase relations; the natural period of the meters was 0.8 sec. The lag of the mechanical action of the

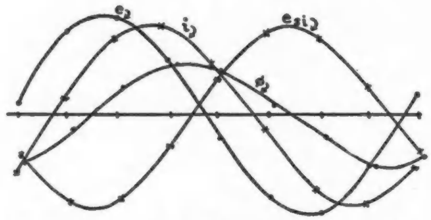


FIG. 4. Sine waves of applied voltage E, current I, self-induced voltage E_{si}, and flux ϕ.

meters behind the electrical action which they were to represent was calculated from the differential equation for forced vibrations of the galvanometers. The lag was 7° for the current meter, which was shunted with a low resistance, and 3° for the voltage meters. The flux meter had no appreciable lag, since its natural period was much higher than that of the forced vibrations. The differential lag of 4° between the current and voltage was not important in the visual demonstration. Corrections for it and for the difference between the voltage and flux readings were made in plotting Fig. 4.

The simple apparatus described fulfills the need for a simple visual demonstration of the phase relations in an inductive circuit, and the comparison of the inductance with the other fundamental elements of an electric circuit. It may serve as a subject for more extended work in thorough analysis of electric and magnetic relations, such as the investigation of non-sinusoidal variations of current with greater fields, and is thus suitable for a physics projects course.

Acknowledgment is due Professor S. J. Plimpton, of the Department of Physics, who suggested the use of low frequency alternating voltage for the demonstration.

The Specific Charge of the Electron by the Thomson Method with a Commercial Cathode-Ray Oscillograph

A. H. WEBER AND J. F. MCGEE*
Department of Physics, St. Joseph's College, Philadelphia, Pennsylvania

THE specific charge of the electron has been discussed in recent articles in this journal.[1,2] The methods presented for measuring this fundamental ratio either have required rather special apparatus or have been intended for demonstration purposes. The method here described is suitable for the advanced undergraduate laboratory and employs standard equipment. The experiment follows that of J. J. Thomson[3] and includes an evaluation of the electric field strength distribution about plane diverging plates such as are found in the cathode-ray tubes of some commercial oscillograph outfits.

In Fig. 1, T is a 3-in. cathode-ray tube, RCA type 906 (the tube alone is shown in more detail in Fig. 2), mounted in a large 7-pin socket S outside the control unit C on an auxiliary support F. The socket is so oriented that a vertical deflection can be produced by the electrostatic deflecting plates nearer the tube screen (D_1 and D_2, Fig. 2). A 7-wire extension cable W soldered to S is plugged in the socket of C to connect the tube with the oscillograph circuit. This cable connects the cathode-ray tube as in normal use, except that the lead L from the deflecting plate D_1 remains unconnected so that a deflecting potential may be applied externally.[4] The companion deflection plate D_2 is grounded as usual through the oscillograph circuit. A set of Helmholtz coils M is used to produce magnetic deflection of the cathode-ray beam. The coils are of average radius 9.04 cm, are 2.5 cm in width, have 60 turns each of No. 16DCC wire, and can be separated to allow insertion of the tube.

---

* Now at Notre Dame University.

[1] K. T. Bainbridge, Am. Phys. Teacher **6**, 35 (1938).

[2] H. D. Smyth and C. W. Curtis, Am. Phys. Teacher **6**, 158 (1938).

[3] J. J. and G. P. Thomson, *Conduction of Electricity through Gases* (Cambridge, 1928), Vol. I, p. 230.

[4] This deflecting plate is above ground potential when the tube is plugged directly into its socket in control unit C. See *RCA Cathode-Ray Tubes and Allied Types*, Tech. Series TS-2, p. 50.

For the measurement of e/m the apparatus is arranged as in Fig. 1 with the axis of the cathode-ray tube in the magnetic N-S line to minimize the effect of the earth's magnetic field. Fig. 2 shows the special electrical connections to the tube. The large dashed circle M represents the Helmholtz coils, which are arranged so that their axis intersects normally the undisturbed electron beam $O'OP$, and are set longitudinally with respect to the tube so that their field falls to zero at O, the outer edge of the horizontally deflecting plates. With D_1 and D_2 grounded and zero current in the Helmholtz coils the oscillograph circuit is adjusted to produce a spot at P on the screen as small and faint as is consistent with viewing. A grounded coat of Aquadag, completely covering the glass part of the tube excepting the screen, will be found helpful. A small magnetic deflection PB_M is now produced with a steady current of about 200 ma in coils M, the deflection being measured with a celluloid metric scale attached to the screen. The deflection is then reduced to zero by applying the appropriate potential across plates D_1 and D_2 with the simple potentiometer circuit shown in Fig. 2. This balancing of the magnetic deflection corresponds, of course, to an equal electrostatic deflection PB_E. The specific charge of the electron then can be calculated by means of the relationship:[5]

$$\frac{e}{m}=\frac{PB_{E\text{ or }M}\int_{O'}^{O'P}\left[\int_{O'}^{x'}Xdx'\right]dx'}{\left(\int_{O}^{OP}\left[\int_{O}^{x}Hdx\right]dx\right)^2}, \tag{1}$$

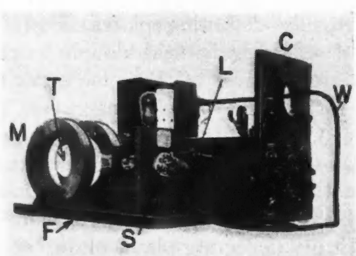


FIG. 1. Photograph of the essential apparatus.

[5] See J. A. Crowther, *Ions, Electrons and Ionizing Radiations* (Arnold, ed. 6, 1934), pp. 92–95; or reference 3, pp. 229–232, for derivation.

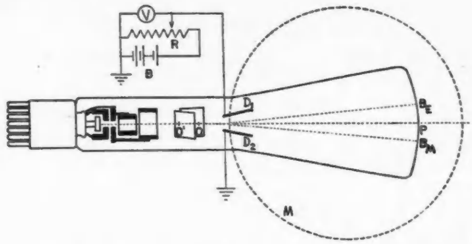


FIG. 2. Diagram of cathode-ray tube showing the connections for producing the electrical deflection and the position of the Helmholtz coils. V, 0 to 25-v voltmeter; R, 7800-ohm potential divider; B, 45-v dry battery.

where X and H are the electric and magnetic field strengths, respectively, and $O'P$ and OP are the distances over which these two variables are effective. The x and x' axes are laid off along the line $O'OP$ (Fig. 2).

Both double integrals of Eq. (1) are evaluated graphically.[6] Consider first the magnetic field double integral. With the cathode-ray tube removed from the stand F of Fig. 1, the magnetic field strength along the radial axis of the central plane of the coils is measured, with a flip coil[7] in series with a ballistic galvanometer and the secondary of a standard solenoid, for the same coil current as produced the deflection PB_M. The experimental curve (A) of Fig. 3 thus is obtained. Using the appropriate interval, OP of Fig. 2, (B) of Fig. 3 is derived and hence the double integral in the denominator of Eq. (1) can be evaluated.

The evaluation of the electric field double integral occasions a little more difficulty. Because of the small size and the divergence of the vertically deflecting plates D_1 and D_2, their end effect is neither small nor readily calculable. The procedure adopted was to construct a brass model of these plates to a scale of 5 and plot the equipotentials about them, using the usual probe method with the plates immersed in a salt solution. An a.c. potential difference of 5 times the experimental d.c. voltage applied to the tube plates was used. Fig. 4 shows some of the equipotentials so obtained. To determine X as a function of x' the central horizontal section of this plot was divided into 5 sets (*1*, *2*, D_1 and D_2, *3*, and *4* in Fig. 4) of equipotentials, which include the entire path (O' to P, Figs. 2 and 4) over which the integral is to be evaluated. The point O' is chosen as the lower limit of the integral, because at this point the electric field strength is very nearly zero. From Fig. 4 it is seen that D_1 and D_2 are radial straight lines and that the other four sets of solid lines are very approximately radial straight lines also. These five sets, therefore, can be treated as radially diverging plane plates, the field at any point between any pair of which is given

[6] B. L. Worsnop and H. T. Flint, *Advanced Practical Physics for Students* (Methuen, ed. 2, 1927), p. 618.

[7] Generously supplied by the Anaconda Wire and Cable Co. The coil had 15,000 turns of No. 40 SSE wire, was 2 cm wide, and had an average diameter of 3.43 cm.

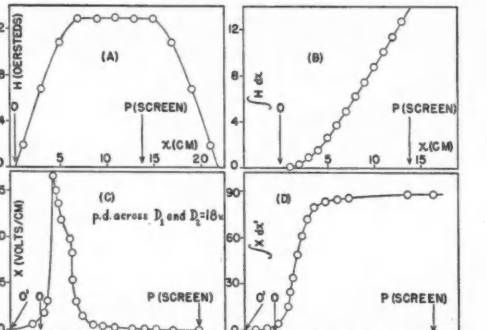


FIG. 3. Graphs used in performing the integrations of Eq. (1). (*A*) and (*B*) are used to evaluate the magnetic field double integral; (*C*) and (*D*), the electric field double integral. The arrows along the abscissa axes indicate the positions of the points O', O and P of Figs. 2 and 4.

by $X=V/d$; here V is the potential difference between the pair of "plates" in question and d is the distance between them measured along a circular arc passing through the point at which the field is being measured and terminating on the "plates," the center of curvature of this arc being the intersection of the "plates" extended. The potential difference between any of the "plates" numbered *1* to *4* in Fig. 4 can be obtained since each equipotential line can be followed until the portion between the brass model plates D_1 and D_2 is reached. The value in volts of every equipotential line within D_1 and D_2 then readily follows from the potential difference between these plates and the distance[8] of the line from D_1.

Figure 3 (*C*) is a graph of the electric field strength measured by the method outlined. Each value of X has been divided by 5 to reduce the scale to unity. Fig. 3 (*D*) is derived from (*C*) exactly as in the magnetic integral case and yields the numerical value of the double integral in the numerator of Eq. (1).

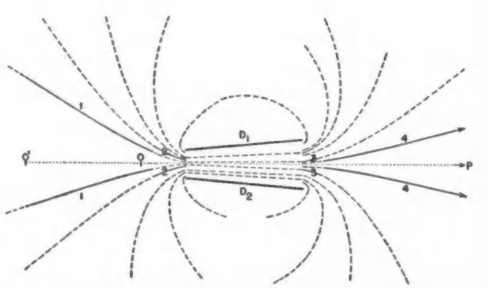


FIG. 4. Equipotential lines about the vertically deflecting plates D_1 and D_2. The arrowheads on the central line $O'OP$ and on the solid lines marked *4* indicate that these lines extend to the cathode-ray tube screen as straight lines.

[8] This distance must, of course, be measured along the *flow* lines between D_1 and D_2. These flow lines, which are not shown in Fig. 4, are circular and normal to D_1 and D_2.

A set of experimental data and the corresponding value of the specific charge of the electron appear below; the necessary distances and dimensions of the tube parts were measured with a cathetometer:

Magnetic deflection, PB_M ...... 0.63 cm;
Current in Helmholtz coils ...... 0.200 amp;

$$\int_O^{OP}\left[\int_O^x H\,dx\right]dx \quad \ldots\ldots \quad 73.68;$$

P.D. between D_1 and D_2 corresponding to curve (*C*), Fig. 3 ...... 18.0 v;
P.D. between D_1 and D_2 to reduce above magnetic deflection (0.63 cm) to zero ...... 23.1 v;

$$\int_{O'}^{O'P}\left[\int_{O'}^{x'} X\,dx'\right]dx' \text{ (for 18.0 v between } D_1 \text{ and } D_2) \ldots\ldots 1166.4.$$

Therefore, from Eq. (1),

$$e/m=\frac{1166.4\times(23.1/18.0)\times0.63\times10^8}{(73.68)^2}=1.74\times10^7 \text{ emu/gm};$$

$e/m=1.7575\times10^7$ emu/gm;[9]
error $=1.13$ percent.

It will usually be found desirable to simplify the experiment: (1) by having the student calculate[10] instead of measure the magnetic field of the Helmholtz coils; and (2) by supplying him with the value of the electric field double integral for a given potential difference between D_1 and D_2. The calculations of (1) have been carried out in the present case as a check and yield a value of e/m agreeing within 3.4 percent with that given above. The second suggested simplification amounts in effect to supplying the student with the end correction to be applied to plane diverging plates, and is thus similar to the practice of applying a correction which appears in the literature and is accepted by the laboratory worker without experimental confirmation on his part. Experimental tests made show that the distribution of electric field strength is not sensibly altered for variations of a few volts in the potential difference applied across the vertically deflecting plates. Therefore the value of the electric field double integral for potential differences of the same order of magnitude as that used in plotting curves (*C*) and (*D*), Fig. 3, can be obtained by direct proportion.

It may finally be noted that the method used in evaluating the electric field double integral is applicable to either plane parallel or plane diverging vertically deflecting plates of any shape and hence can be applied to practically all commercial cathode-ray tubes.

[9] R. T. Birge, Phys. Rev. **48**, 918 (1935).
[10] Using Eqs. (1) and (2) of reference 1.

DISCUSSION AND CORRESPONDENCE

A "Minimum of Mathematics" in School Science

PROFESSOR Perkin's protest[1] of the tendency to minimize mathematics in the first courses in college physics leads me to remind the American Association of Physics Teachers that mathematics is getting as bad, or worse, treatment in the hands of many curriculum builders in science at the secondary and elementary levels. Those who are in charge of an integrated science program from the first to the twelfth grades are eliminating mathematical computations. They assume that science students cannot perform the simplest multiplications and divisions.

The same mental processes that enable a boy to keep from being short-changed at a store can, I maintain, be used in physical science in connection with such equations as $s=vt$ and $D=M/V$; and the boys *are* taught in arithmetic to make change. If the curriculum builders would permit us to assume that students can multiply and divide, it would be of help; yet an examination of the new books on science (there are no old ones at the elementary level) will show that not even these simple processes are employed. Educators do not seem to be aware of the fact that the sciences offer a way to make the students' mathematics function, and that mathematics in turn serves to make the study of science quantitative and meaningful.

CARL A. BENZ

Hammond High School,
Hammond Indiana.

[1] Am. Phys. Teacher **6**, 275 (1938).

Simplified Use of Cycles in Thermodynamics

IN THE application of thermodynamic laws to special cases use is often made of a cycle, and this method has certain advantages of brevity and concreteness over other more abstract methods. A Carnot cycle is often employed; but this is open to the objection that under some circumstances the nature of the two adiabatic changes is not immediately obvious. A simplified method of using cycles of other types has been found convenient by the writer, and may perhaps be of interest to others. It does not seem to occur in the textbooks.[1]

The two laws of thermodynamics, applied to any reversible cycle, are equivalent to the familiar equations,

$$W=\oint dQ, \qquad \oint dQ/T=0, \tag{1}$$

where T is the absolute temperature, dQ is the element of heat absorbed by the substance, and W is the work done by it during the cycle. Multiplying the second of these equations by T_0, which represents *any convenient* fixed temperature, and then subtracting the multiplied equation from the first one, we can write as the result

$$W=\oint \frac{T-T_0}{T}dQ. \tag{2}$$

By means of this formula results can be obtained very quickly from many cycles of non-Carnot form, the arbitrary temperature T_0 being made equal to T along some part of the path in order to eliminate the contribution of that part to the integral. The equation obviously constitutes a generalization of the familiar formula of Carnot theory, $W=(T-T_0)Q/T$. It is especially useful in recovering quickly a formula that has been forgotten. Two illustrations of its use follow.

Imagine the space above a liquid, empty except for the saturated vapor of the liquid, to be increased in volume while the temperature T is kept constant, until unit mass of liquid has evaporated. Then let everything be cooled to $T-dT$, the volume occupied by liquid and vapor being held constant; let the space be contracted again without change of temperature; and finally let everything be heated at constant total volume to T. By means of the usual devices all of these steps can be carried out in a reversible manner. Such a cycle is easier to conceive than a Carnot cycle under the given circumstances. Then, if $p-dp$ denotes the vapor pressure at $T-dT$, the net work dW done during the cycle is $dp\,\Delta V$, where ΔV is the increase of volume of unit mass in vaporizing. The contributions of the heating and cooling to the integral in Eq. (2) are negligible in the limit as $dT\rightarrow 0$ if we take $T_0=T-dT$, both the integrand dT/T and the range of integration being infinitesimals of the first order. Hence we can write for the integral simply $L\,dT/T$ in terms of the heat of vaporization L. Thus, $dp\,\Delta V=L\,dT/T$ and we have Clapeyron's equation,

$$dp/dT=L/T\,\Delta V. \tag{3}$$

As a second example, let us deduce Stefan's law. Let an evacuated vessel with one wall movable like a piston be expanded by unit volume, its temperature T being kept constant. During this process the radiant energy in the vessel does work numerically equal to the radiation pressure p; and the system absorbs heat equal to the sum of this work and the increase in radiant energy, or to $p+u$, where u is the density of the radiation. Now cool to $T_0=T-dT$ without moving the wall, contract by unit volume at constant temperature and at pressure $p-dp$, and heat to T. Then the net work is dp, the integral in Eq. (2) is, in the limit, $(p+u)dT/T$, and, by Eq. (2), $dW=dp=(p+u)dT/T$; inserting as usual $p=u/3$, we find

$$\tfrac{1}{3}\,du=(4/3)u(dT/T), \qquad u=aT^4. \tag{4}$$

E. H. KENNARD

Cornell University,
Ithaca, New York.

[1] An approach to the formula given here occurs in Bryan's *Thermodynamics* (Teubner, 1907), p. 87.

Centrifugal Force

C. F. HAGENOW has demonstrated in an article, "Is There a Centrifugal Force,"[1] that textbooks of physics give obscure discussions of the concept of centrifugal force. Hagenow defines centrifugal force as the reaction to the centripetal force which acts on a body moving in the circumference of a circle with constant speed. He also refers to the inertial force which is introduced in order to transform a problem of acceleration into one of equilibrium. It is hoped that the present note will contribute to further clarification.

Suppose that a particle attached to the end of a cord moves in the circumference of a circle with constant speed. The particle has an acceleration directed towards the center and therefore, by Newton's second law, is acted upon by a centripetal force, the force in the cord. The term *centrifugal force* is employed in two distinct senses. As exemplified by Hagenow's discussion, centrifugal force may be defined as the reaction to the centripetal force; centrifugal force then is not a force acting on the moving particle, but is the force of reaction (Newton's third law) of the moving particle on the body exerting the centripetal force. Centrifugal force may also be defined as an outward force acting on the particle, and is balanced by the inward centripetal force; in its second sense, centrifugal force and centripetal force act on the same body. Centrifugal force defined as reaction to centripetal force is real,[2] but defined as the equilibrant of centripetal force, is fictitious.

The explanation of the foregoing distinction is in terms of different frames of reference to which the motion is referred.

The laws of motion of classical dynamics hold only with respect to inertial frames of reference. Such frames, which may have constant translational velocities with respect to one another, occupy a privileged position. An inertial frame is exemplified by the astronomical one whose origin is at the center of mass of the solar system and whose axes are fixed with respect to the "fixed" stars. For purposes of illustration, however, the earth, which rotates with respect to the astronomical frame, may be mentioned as a frame in which the laws of classical dynamics hold approximately. Let us now suppose that with respect to an inertial frame K, a particle of mass m moves in a circle with constant linear speed v and therefore constant angular speed $\dot{\phi}$. By Newton's second law the centripetal force F is $-mr\dot{\phi}^2$, the minus sign indicating that the force is inwards. The particle may be thought of as attached to a spring balance which indicates the calculated centripetal force. Suppose that a second frame K' with origin at the center of the circle rotates relatively to K with constant angular speed ω about an axis perpendicular to the plane of the circle. If $\dot{\theta}$ is the angular speed of the particle about the same axis with respect to K', $\dot{\phi}=\dot{\theta}+\omega$. In terms of the new variables the expression for the centripetal force $F=-mr\dot{\phi}^2$ becomes

$$F=-(mr\dot{\theta}^2+mr\omega^2+2mr\dot{\theta}\omega). \tag{1}$$

The foregoing equation was set up for the frame K. Let us now consider the equation of motion with respect to the frame K'. Relative to K' the angular speed is $\dot{\theta}$ and the centripetal acceleration is $-r\dot{\theta}^2$. We may consider two cases. First, suppose that the particle is at rest in K'. This case may be realized by a particle at rest at the end of a spring balance on a platform which is rotating with constant angular speed with respect to the surface of the earth. Then $\dot{\theta}=0$, hence the centripetal acceleration referred to K' is zero; but, by Eq. (1), $F=-mr\omega^2$. That this latter force acts on the particle may be determined by an observer on K' who reads the spring balance. But now the second law of motion fails to hold, in the sense that a force acts on the particle and yet there is no acceleration relative to K'; K' is not a permissible frame of reference for classical dynamics. We may, however, apply the second law relative to this nonpermissible frame if we assume that there is acting on the particle an outward force $mr\omega^2$. This centrifugal force is balanced by the inward centripetal force exerted by the spring, so that the total force is zero. The introduction of the centrifugal force preserves the second law in a rotating frame of reference, but the third law appears to be violated. What is the reaction to this centrifugal force and on what body does the reaction act? Classical dynamics does not enable one to answer these questions without *ad hoc* hypotheses. The centrifugal force is therefore viewed as an imaginary or fictitious force.

As a second case let $\dot{\phi}=0$ so that the particle is at rest in the system K. Then $\dot{\theta}=-\omega$ and, by Eq. (1),

$$F=-(mr\omega^2+mr\omega^2-2mr\omega^2)=0. \tag{2}$$

In agreement with this calculation the spring balance to which the particle is attached will register zero force. Relative to K' the particle has a centripetal acceleration $-r\dot{\theta}^2=-r\omega^2$. If the second law is to hold for K', we must assume that an inward force $-mr\omega^2$ is acting. On transforming Eq. (2) into $-mr\omega^2=-2mr\omega^2+mr\omega^2$ it is apparent that the assumed inward force may be viewed as the sum of an inward Coriolis force $-2mr\omega^2$ and an outward centrifugal force $mr\omega^2$. This force does not satisfy the third law, because one cannot point out the reaction or the body upon which the reaction acts. Furthermore, the spring balance fails to register the calculated force. Clearly this inward force must be viewed as fictitious.

The foregoing results are also obtainable by the Lagrange equations. The kinetic energy must be expressed for the system K. If the coordinate $\dot{\theta}$ is used to describe the motion of the particle relative to the rotating frame, the expanded expression for the kinetic energy contains terms that must be transferred to the expression for the generalized component of force in order to preserve the form of the Lagrange equations for the rotating frame of reference.

In the opinion of the writer it would be desirable to restrict the term centrifugal force to the fictitious force in a rotating frame of reference. In any event, it is an error to define centrifugal force as the reaction to centripetal force and then later to use it in the sense of the fictitious force. This error occurs in at least one contemporary text.

V. F. LENZEN

University of California,
Berkeley, California.

[1] Am. Phys. Teacher 3, 190 (1935).

[2] The term *real* may need explanation. If the product of mass and acceleration is functionally related to specific physical conditions in the environment, such as the extension of a spring, a real force is said to act on the mass. The physical situation in which a force is acting is not changed if mechanics is developed without introducing the concept of force.

Proceedings of the American Association of Physics Teachers

The Washington Meeting, December 28–30, 1938

THE eighth annual meeting of the American Association of Physics Teachers was held at the National Bureau of Standards, Washington, D. C., on December 28–30, 1938. The presiding officers were F. K. Richtmyer, President of the Association, and H. B. Lemon, Vice President.

A joint dinner with the American Physical Society and Section B of the American Association for the Advancement of Science was held at the Wardman Park Hotel on Wednesday evening, December 28.

Two interesting features of the meeting were the inspection of the standards in the laboratories of the National Bureau of Standards and the exhibit of 62 pieces of laboratory and lecture-demonstration apparatus arranged by the District of Columbia and Environs chapter of the Association. Institutions that contributed to this exhibit included American University, Catholic University of America, Central High School of Washington, Episcopal High School of Alexandria, Georgetown University, George Washington University, McKinley High School of Washington, and Roosevelt High School of Washington.

In a ceremony held at the National Bureau of Standards on Friday morning, December 30, President Richtmyer and D. L. Webster, Chairman of the Committee on Awards, presented the 1938 Award for Notable Contributions to the Teaching of Physics to *Alexander Wilmer Duff*. The addresses and remarks made during the ceremony appear elsewhere in this issue.

Invited Papers

The following invited papers were heard at two of the sessions:

Society and the Intelligent Physicist. P. W. Bridgman, *Harvard University*.

The Physicist in the Government Service—A Symposium. E. C. Crittenden, *National Bureau of Standards;* H. G. Dorsey, *Coast and Geodetic Survey;* E. O. Hulburt, *Naval Research Laboratory;* C. H. Kunsman, *Fertilizer Research Division, Bureau of Chemistry and Soils.*

Two invited papers were presented at the joint sessions with Section B, A. A. A. S., and the American Physical Society:

The National Standards of Measurement. Lyman J. Briggs, *National Bureau of Standards*.

Auditory Patterns. Harvey Fletcher, *Bell Telephone Laboratories*.

Contributed Papers, with Abstracts

Two sessions were devoted to the following contributed papers:

1. Problem Forms as a Teaching Aid. G. P. Brewington, *Lawrence Institute of Technology, Detroit, Mich.*—A problem sheet for issuance to students has been developed. Blank spaces are provided at the top of the sheet for the student's name, section, and course number, and for the date the problems are due. The date, which is inserted by the instructor with a rubber stamp, serves as a classifying symbol and as a constant reminder to the student to get the work in on time. The problems may consist of either the conventional type or those in which only a figure or diagram is given. Blank spaces are provided for the answers; thus no time is lost in looking for answers, and grading becomes more or less routine. The problems are to be worked on separate sheets of paper and attached to the form sheet; thus the student's actual work is available if any question arises in the grader's mind. Several final examinations have also been given on forms of this type and are found much easier to grade. Students seem to enjoy working with these forms; they work about twice as many problems as when the problems are assigned from textbooks. The diagram problems attract their attention. A box to receive all problems and laboratory reports should be provided.

2. Kirchhoff's Laws and the Principles of Statics. Ira M. Freeman, *Central Y. M. C. A. College, Chicago, Ill.* (*Introduced by Vergil C. Lohr.*)—An instructive analogy is pointed out between the conditions for the complete equilibrium of a rigid body acted upon by external forces and the steady flow of electricity in a network. The requirement that the sum of the forces should vanish in the mechanical case is similar to Kirchhoff's first law for networks, while the equilibrium of torques is formally identical with Kirchhoff's second law. The parallel roles of the defining equation for torque and Ohm's law are indicated, and the discussion is correlated with recent remarks by Summers [Am. Phys. Teacher **6**, 282 (1938)] and Stephenson [Am. Phys. Teacher **6**, 217 (1938)] concerning the relation of Ohm's law to Kirchhoff's second law.

3. A Simple Device for Demonstrating the Components of a Vector. Wilfrid J. Jackson, *N. J. C., Rutgers University, New Brunswick, N. J.*—For demonstrating the components of a vector [Sutton, *Demonstration Experiments in Physics*, p. 16], a simple apparatus has been constructed as a single unit, thus saving much time in setting up the class demonstration. A thin wooden arrow, 40×1.5 cm, is mounted on a board 75×85 cm and made to rotate about one end by means of a double lever arrangement on the back of the mounting. To one end of this double lever is attached a second, slotted arrow, also 40×1.5 cm, which is arranged to slide horizontally. The end of a third arrow is attached to the end of the rotating arrow and is kept vertical by means of a wire mounted on the back of it which passes through a ring in the end of the horizontal arrow. As the horizontal arrow shortens and the vertical arrow lengthens, that part of the horizontal arrow beyond the axis of rotation is kept out of view by having it move under a suitably mounted board. By a similar arrangement, that part of the vertical arrow below the horizontal arrow is kept out of view. The slotted arrow could be made to slide in any desired direction,

other than horizontal, to demonstrate components of a vector that are not at right angles. When the first arrow is rotated the class can watch one component grow as the other decreases. When one component is equal to the magnitude of the vector and parallel to it, the other is zero. The arrows are painted white to contrast with the mounting.

4. A Two-Year Sequence for the General Course in College Physics. Thomas B. Brown, *George Washington University, Washington, D. C.*—The general course at George Washington University is described. In one two-year sequence (4 one-semester units, totaling 11 credit-hours) this course supplies the curriculum requirements of the engineering and the premedical courses, as well as those of students majoring in the sciences. Each unit is complete in itself (aside from dependence upon previous units as prerequisites) and the nonscience student may elect one or more units as he pleases. The fourth unit is a brief introduction to modern physics, which serves also as a thorough review and integration of the fundamental principles studied in earlier units.

5. The Dilemma of Method *Versus* Subject Matter. Rogers D. Rusk, *Mount Holyoke College, South Hadley, Mass.*—The recent expansion of subject matter and procedure in physical science, together with a widespread re-awakened interest in scientific methodology, has led to an apparent dilemma which clearly resolves itself into a demand for a new emphasis on method and on the meaning of both method and subject matter. The recent expansion of subject matter would seem more than ever to preclude adequate attention to problems of logical procedure and the analysis of fundamental concepts; at the same time, the extension of physics to realms further and further removed from direct sense perception and the accompanying growth of procedure and concepts have revealed a new and rapidly growing need for such attention to logical problems. The development of the operational viewpoint and the inclusion of the observer in the relativity and quantum theories have resurrected inescapably the ancient philosophic problem of the knower and the known; and such developments demand that the physicist and teacher become more critical of the knowing process and take cognizance of the subjective, as well as the objective, elements in scientific procedure. For example, the problem of reality is not so simple as it was when Newton defined mass, in a preliminary manner, as the product of density and volume. Today the question of reality must be applied to such diverse entities as electrons, neutrinos, waves in phase-space, quanta, and red-shifts. Meanwhile, even such concepts as mass and force are considerably refined and deserve to be handled with much more care than is given in some recent texts. Although the teacher of the general course cannot ordinarily become a specialist in the methodology of physics, it is his obligation to avoid common pitfalls and become acquainted with the fundamentals of modern logical procedure.

6. A *P-V-T* Model of the Allotropic Forms of Ice. Frank L. Verwiebe, *Vanderbilt University, Nashville, Tenn.*—A 3-dimensional model, built to scale, of the *P-V-T* relationships for the 6 known allotropic forms of ice is presented. The model facilitates the visualization of the complex thermodynamic surface representing the various stable phases of ice. The triple points, transition ranges, and volume changes of all the known varieties of ice are apparent by inspection. The data for the model were gathered from the publications of Bridgman. Attention is also called to interesting features of the characteristics of ice, such as its maximum expansive force, the crystallographic data from the x-ray analyses of ice_{I}, ice_{II}, and ice_{III}, with their bearing on glacier movement theories, and the possibility of the existence of ice_{VI} in living tissues.

7. A Simple Derivation of the Maxwell-Boltzmann Law. E. U. Condon, *Westinghouse Research Laboratories, East Pittsburgh, Pa.*—The Maxwell-Boltzmann law is derived in a direct and simple way from the usual postulates that the mechanical system has a discrete system of allowed states and that each of these states has equal *a priori* weight in the calculation of statistical averages.

8. Objectives and Limitations in the Simplification of Letter Symbols—A Report of the Subcommittee on Letter Symbols and Abbreviations. Harold K. Hughes, *Bard College, Columbia University, Annandale-on-Hudson, N. Y.*—The use of inconsistent symbolism has long been a recognized difficulty, not only in the teaching of undergraduate physics, but in the reading of journals and treatises. Thus, while the primary objective of a unified list of letter symbols is to simplify the study of undergraduate physics, a second objective is to endeavor to choose the symbols so that they will be met with the same meaning. To a research worker, one big advantage of standardized symbols is ease in reading an article the first time; the definitions of the symbols, which usually should be included in the article, then serve merely as a reminder or assurance. More than 600 quantities are represented in equations in undergraduate physics. Though many of these never appear in the same discussion, the 100 available symbols do not suffice for a completely unambiguous representation, even allowing for the use of subscripts. The committee finds, moreover, that there is a need for alternate symbols. The committee has agreed that in specialized or rapidly developing fields where the number of workers is relatively small, no symbol shall be recommended unless the concept it represents is well established and there is some measure of uniformity in the symbol used. A copy of Report No. 2 of the subcommittee may be obtained by addressing the author.

9. The Basis of Physical Quantities. J. G. Winans, *University of Wisconsin, Madison, Wis.*—The introduction of physical quantities based on length, mass, and time offers difficulties, such as the confusion of mass and weight, with unsatisfactory definitions of density and of units of mass and force. The confusion and difficulties disappear for physical quantities based on length, force, and time, with mass defined as *force/acceleration*. Length, force, and time are considered as indefinable fundamental experiences; and other physical quantities are defined as algebraic

combinations of these. This makes possible a logical development of definitions and units. Additional indefinable experiences are electric charge and magnetic pole strength. Electric and magnetic physical quantities are defined in terms of charge, magnetic pole strength, and the quantities based on length, force, and time. This basis for physical quantities has been found to be more teachable and less confusing to students than the system based on length, mass, and time.

10. Misconceptions in the Field of Temperature Radiation. A. G. Worthing, *University of Pittsburgh, Pittsburgh, Pa.*—(1) That absorption of light rays is not accompanied by thermal effects; the terms, "heat rays" and "cold light," probably are largely responsible for this point of view. (2) That radiations from hot bodies are described by the fourth power law. (3) That a radiating body receives energy from its surroundings in proportion to T_0^4. (4) That Stefan discovered the fourth power law. (5) That Jeans was a major partner in the development of the Rayleigh-Jeans law, $R_\lambda = 8\pi k\lambda^{-5}(\lambda T)$. (6) That the spectral radiancy of a blackbody for a given wave-length varies as T^4. (7) That blackening a light source increases its luminous efficiency. (8) That light sources of uniform temperature are of the same brightness whatever the direction of viewing. (9) That colored objects illuminated by white light reflect, predominantly, light of corresponding spectral colors.

11. An Opportunistic Physics Laboratory. John A. Eldridge, *University of Iowa, Iowa City, Ia.*—Although the greatest opportunity for teaching physics lies in the laboratory, the traditional laboratory tends to degenerate into a mere mechanical routine—following a manual in cookbook fashion and teaching little; not valued by the students and criticized by educators. Experiments are assigned from habit, because they are written up in the manual and the apparatus is available. The author recommends a new attitude toward the laboratory. It should be coordinated closely with the lecture classes, meet student difficulties arising each week, cover more territory, and provide opportunity for concentrated teaching of physics. Physics is so large a subject and time is so short that we cannot afford to let the laboratory drift along as an instrument of questioned value but should make it an integral part of the teaching program.

12. On Teaching the Scientific Method. R. J. Seeger, *George Washington University, Washington, D. C.* (By title.)—Social studies are concerned at present with the development of a method of solving social problems. It is essential, therefore, that students acquire from physicists themselves a clear understanding of the scientific method as used in the physical sciences. This paper discusses the failure of the average text to give a clear conception of the essential nature and limitations of the scientific method. This failure is the result not only of omissions but also of the careless use of words. For example, one text speaks of the "*law* of conservation of momentum"; another, of the "*principle* of conservation of momentum"; and a third states that "there are *no laws* of nature." It is suggested that much of the confusion comes from the employment of traditional words and phrases instead of logical ones.

13. Study of Accelerated Motion by Photography. I. Walerstein, *Purdue University, Lafayette, Ind.* (By title.)—A study of linear accelerated motions of various types has been made photographically. The moving body—a small cylinder containing a flashlight battery, socket, and flashlight bulb—is photographed by means of an inexpensive camera. In front of the camera lens is placed a cardboard disk attached to the shaft of a synchronous motor. The disk has a slot in it so that a series of photographs of the moving flashlight are obtained at intervals of 1/30 sec apart. The flashlight bulb is made to move close to the edge of a meter scale which is therefore photographed on the same film. By using high speed film and a small slot in the disk giving exposures of 0.0005 sec, the images of the flashlight were found to be distinct opaque dots. With the disk rotating, the image of the meter scale is obtained under ordinary illumination in about ½ min. The lens of the camera need not be of good quality since any distortion in size at the edges of the image will affect equally the spacing between the dots and the length of the divisions on the meter scale. The positions of the dots, correct to 0.5 mm, are found by direct comparison with the meter scale. The determination of g and the verification of $F=ma$ by a modified Atwood machine have been made with an accuracy of 1 percent. The apparatus lends itself easily to photographing the path of a projectile against a cross-ruled background; the independence of vertical and horizontal motions is thus directly demonstrated. The variation in velocity in any of the foregoing motions is shown by using a rotating disk with two slots separated by 45°, which produce double images of the flashlight. Rotary motion requires special devices to cut off the images at the end of one period. In the case of simple harmonic motion this has been achieved by using half of a complete oscillation of a pendulum. Using the two slots, the photograph shows the variation in velocity and acceleration along the path. The apparatus is suitable for the elementary laboratory, as well as for demonstration. The time required for development can be reduced by raising the temperature of the developer, and the film can be projected before the class within a few minutes after taking the photograph.

14. Simple Harmonic Motion in the Elementary Laboratory. Winthrop R. Wright, *Swarthmore College, Swarthmore, Pa.*—Elementary experiments on simple harmonic motion are generally confined to the relation of the period to the mechanical constants of the system. Shockley [Am. Phys. Teacher **4**, 79 (1936)] has described an apparatus with which the important aspects of displacement, velocity, acceleration, and energy also may be ascertained; but the apparatus is elaborate and its use will be restricted. In the method to be described each student is given a short helical spring, of stiffness about 100 gm/cm, which he calibrates statically. He computes the mass required to give the system a period of 0.600 sec.

The spring and mass are then mounted by the instructor near a vertical kymograph on which is stretched a length of 2-in. chronograph paper. The mass is set vibrating with an amplitude of about 2 cm and a record of 10 vibrations is made, using a 1/20-sec spark. From this record the student can determine the period to the nearest 0.001 sec. He measures a representative cycle in detail and plots curves for displacement *vs* time, velocity *vs* time, and acceleration *vs* displacement. The maximum velocity indicated by the second curve is checked against its value as predicted from the amplitude and period. The slope of the acceleration-displacement curve is checked against the constants of the system. Data are also available for computing the energy at selected points throughout the cycle.

15. Quantitative Experiments in Elementary Photography. Agnes Townsend, *Barnard College, Columbia University, New York, N. Y.*—A few quantitative experiments in the early part of a course in elementary photography have been found to give the students a much better background for later work than do the more usual qualitative experiments. Some kind of shutter-speed testing is part of almost every photography course but the following three experiments have seemed to be very helpful also. (1) *H*- and *D*-curves for various conditions are determined by the students, using a sensitometer for exposing film strips and a simple densitometer for measuring the opacities of the developed strips; the actual experimental determination of such characteristic curves shows the student the advisability of time and temperature control, the meaning of gamma, and some essential differences between emulsions. (2) The near and far depths of field for several lens apertures and object distances are determined. Test charts made in geometrically scaled sizes and set up at proper distances from the camera give equal sized images when photographed. The depth of field corresponding to some chosen diameter of circle of confusion can be noted from the photograph and compared to the calculated depth of field. Photographs taken at various apertures or with the charts set at different distances show how the depth of field increases with f number and object distance. (3) Several test charts are set up in a row across the field of view at a definite distance from the camera which is focused upon the central card. Other rows of charts are set up at small distances from the first. A photograph taken of such an array can be examined for maximum resolving power, flatness of field, and quality of the image.

16. Complementary Color Photography. Everett F. Cox, *Colgate University, Hamilton, N. Y.*—Demonstrations of complementary colors are usually performed by rotating color disks or projection of light through filters [R. M. Sutton, *Demonstration Experiments in Physics*, p. 408]. A more spectacular and amusing demonstration can be readily arranged by loading Dufaycolor film into two cameras and taking identical pictures with the cameras. One roll of film is then processed by regular reversal to become a "natural" color transparency; the other roll is processed as any normal negative and becomes a "complementary" color transparency. Complementary pairs should be bound side by side between lantern slide plates to allow simultaneous projection. Local views, portraits, photomicrographs, and spectra may all be so photographed to give an interesting collection of material for classroom projection.

17. Color Experiments with a Lecture Table Lantern. V. E. Eaton, *Wesleyan University, Middletown, Conn.*—An easily constructed attachment for a Model B Delineascope converts it into a color mixer. The single mirror is replaced by a flat plate set at an angle of 45°. Through this plate, and attached to it by ball-and-socket mountings, project 3 stems. A 5×6-cm mirror is mounted on the lower end of each stem. An opaque screen with three 2-cm circular holes, so disposed that the light from each hole falls on one of the mirrors, is placed on the lantern slide holder. A color filter is placed over each hole. With this arrangement 3 intense colored disks are projected on a screen of flashed opal glass and the position of each can be varied at will. Inexpensive filters are made by mounting $1\frac{3}{4}\times1\frac{3}{8}$ in. gelatin film filters in No. 828 Kodaslide frames. If a pair of Polaroids, one of which may be rotated, is mounted over each hole, the intensity of the light may be controlled. To illustrate the additive process of color photography 3 photographs are taken through the proper filters with a miniature camera and positives made on photographic plates. Each positive is placed over one of the holes and covered with the proper filter. The 3 mirrors are used to register the 3 colored images on the screen. The subtractive process of color photography is illustrated by means of colored slides.

18. Phonoptic Equipment for Individual Student Use. Harold K. Schilling, *Union College, Lincoln, Neb.*—While for lecture-demonstration purposes apparatus should be large, for individual student use in the laboratory it should be small in dimensions, to facilitate storage and conserve laboratory table space, and inexpensive, to make possible the construction or purchase of duplicate sets. It has been found possible to perform successfully most of the phonoptic experiments described thus far with apparatus which in these respects is much more satisfactory than that exhibited at Indianapolis [Am. Phys. Teacher **6**, 156 (1938)]. A source box 52×23×23 cm, lined with absorptive material, is suitable. Furthermore, operation may be simplified by the use of electrically actuated sources under conditions to be described. Piezoelectric speakers have yielded satisfactory results up to frequencies of 15,000 sec^{-1}. Relative intensities may be measured with satisfactory accuracy by means of a crystal microphone, amplifier, and rectifier-type voltmeter assembly. The usefulness of the apparatus is greatly enlarged by the use of the electric source. Thus Colwell's method of measuring the speed of sound [Colwell, Friend, and McGraw, J. Franklin Inst. **225** (1938)], the existence of a temperature coefficient of the speed of sound, and the possibility of acoustic filtration can be readily demonstrated.

19. Two Simple Devices for Measuring Time Intervals in a Physical Laboratory. Robert M. Woods and Noel C. Jamison, *Northwestern University, Evanston, Ill.*—The first device is an electrical stop watch for measuring intervals

from 0.1 to 0.001 sec. This consists of three parts: (1) the stop watch proper, which is a Western Electric telephone message counter mounted in a suitable case with a toggle switch and a cord and plug for attaching to the wall outlets situated around the laboratory; (2) the power supply, which may be either a 50-v dry battery or a suitable rectifier system; (3) a Bodine synchronous motor with reduction gears to give a final speed of 10 rev/sec; mounted on this shaft is an eccentric which in turn operates a pair of contacts; the time of contact is adjustable, but about one-half of the time open and one-half closed is found to be correct. These three parts, connected in series, give a rugged accurate stop watch that counts tenths of seconds directly, with an error of not more than 0.2 sec. A complete unit consisting of the rectifier system and one counter can be assembled at a cost of about $45 for parts. Additional counters cost about $4 each. Once assembled there is practically no upkeep cost and the counters can be handled roughly or even dropped from a table to the floor with little or no damage. The second device is a photoelectrically controlled relay for obtaining second impulses from a clock pendulum. This device was constructed from standard radio parts with the exception of the relay and the photoelectric cell. The cell is a commercial vacuum cell and is connected in the grid circuit of a 47-type tube. An 80-type tube is used as a rectifier in the power supply, which need not be filtered. The relay is a Western Electric relay which operates on about 10 ma. The illumination for the photoelectric cell is furnished by a standard automobile headlight bulb. All voltages required in the unit are supplied by a standard radio power transformer. The cost of the parts in this unit was about $15.

20. A Brief Survey of Possible Methods of Harmonic Analysis and an Adaptation of One for Fine Arts Students. Louis R. Weber, *Colorado State College, Fort Collins, Colo.*—In giving a course for students of fine arts, the author believed that a way could be found for students with little background or laboratory skill in physics to study musical instruments as one of a number of laboratory experiments. They should be able to find not only the principal harmonics present but also how the shape of the instrument or organ pipe affects the intensity of these harmonics. Of the methods available, some had to be eliminated because of the expense, or because they were unstable or too difficult to operate. The method finally developed depends upon well-known stroboscopic principles. It is rapid, stable, very easy for beginners to operate, and involves equipment available in the modern laboratory. So far, only the first 10 harmonics have been used but these were sufficient for the purpose intended.

21. The Cathode-Ray Oscillograph as an Aid to the Study of Some Electrical Principles. Herbert Trotter, Jr., *Washington and Lee University, Lexington, Va.*—Methods are described for studying: (a) the charging of a condenser through a resistance and self-inductance; (b) the aperiodic and oscillatory discharges of a condenser, the latter being useful in explaining the operation of a Tesla coil; (c) the phase relation of current and voltage in a circuit containing variable capacitance, self-inductance, and resistance; and (d) the principles of wireless communication.

22. The Theory of the Triode as a Three-Body Problem in Electrostatics. Alexander Marcus, *College of the City of New York, New York, N. Y.*—The usual elementary textbook explanation of the action of the control electrode in a triode, in which the function of the grid as a control electrode is attributed entirely to its influence upon the space charge, leads students to believe that the grid must be placed between the filament and plate if it is to act as a "traffic regulator" of the electron stream in the tube. Experiment shows, however, that amplification can be secured when the grid and anode are on opposite sides of the filament, which is to be expected if account is taken of the effect of the bound charge on the filament.

23. Student Projects in the Physics Shop. G. P. Brewington, *Lawrence Institute of Technology, Detroit, Mich.*—The interest that many students have in constructing apparatus can be used to advantage in building equipment useful in almost any physics department. Moreover, the students seem to be more careful with apparatus built by their classmates. The following construction projects lend themselves readily to student participation. (1) Several blocks of wood of such dimensions that at certain accelerations some of the blocks will just fall. (2) Simple apparatus for studying the bending of a beam; as an experiment this introduces the student to log-log paper. (3) Simple viscometer. (4) Mounting of an automobile transmission, an ideal laboratory experiment on combinations of machines. (5) Improved apparatus for obtaining the temperature-time curve for cooling through a change of state. (6) Apparatus for determining the adiabatic constant. (7) Manufacture, and calibration, of a resistance box from commercially available radio parts. (8) Convenient mountings for electrical meters; to date, they have practically eliminated theft. (9) The 15-point switch developed for certain multiple range meter sets has been adapted to form a convenient rheostat for use in the step-by-step method of obtaining hysteresis curves. (10) Useful multiple terminals, made by fastening several different types of binding posts to small square brass plates mounted on a wooden base. (11) Lamp house or light source.

24. The Teaching Effectiveness of the Sound Motion Picture, *Electrons*. C. J. Lapp, *State University of Iowa, Iowa City, Ia.*—The teaching effectiveness of the sound motion picture, *Electrons* (Erpi Picture Consultants), has been studied in detail. Objective tests, consisting of items built around principles presented in the film, were given, before and after seeing the film, to 107 students of college physics who had not studied electrical theory in college. The statistical methods were similar to those worked out for a previously reported study of the film, *Electrodynamics*. The learning achievement for 24 distinct facts produced by the film was found to be: above 85 percent for 3 facts; 70 to 85 percent for 5; 50 to 70 percent for 9; 50 percent to zero for 4; and zero or negative for 3. Students who were supplied with a mimeographed study sheet directing attention to vital parts of the film made a 30 percent

better gain in learning than did a matched group that did not have the sheets

25. "Superficiality" in Physical Science Courses Offered for Purposes of General Education. Louis M. Heil, *University of Chicago, Chicago, Ill.* (By title.)—During the last decade there has been a significant increase in the number of physical science courses offered for the student who is not specializing in a science. Recurrently during this time, the issue of whether such courses are "superficial" has been debated, the controversy often centering in the issue of whether the new courses are courses "in science" or simply "about science." Differences of opinion will probably continue and become more intense unless some effort is made to clarify the assumptions implicit in this issue of "superficiality." Clarification of these assumptions should lead to the following results: (a) a clearer basis for a stand on the issue of "superficiality"; (b) an indication of the kind of experimental evidence necessary to test those hypotheses or assumptions which are basic to the issue of "superficiality"; (c) a clearer direction for those who are offering courses for purposes of general education.

Attendance

The registration of those in attendance lists 122 members of the Association and 22 non-members. Members who registered were:

G. H. Bancroft, Hobart College; H. A. Barton, American Institute of Physics; R. M. Bell, Washington and Jefferson College; F. A. Benedetto, Spring Hill College; C. E. Bennett, University of Maine; D. M. Bennett, University of Louisville; J. G. Black, Morehead State Teachers College; F. C. Blake, Ohio State University; H. J. Bolger, University of Notre Dame; F. I. Brady, Georgetown University; M. L. Braun, Catawba College; G. P. Brewington, Lawrence Institute of Technology; F. L. Brown, University of Virginia; A. B. Cardwell, Kansas State College; W. E. Chamberlain, Temple University Medical School; W. L. Cheney, George Washington University; C. E. Cleeton, U. S. Naval Research Laboratory; F. E. Cleveland, Lynchburg College; E. U. Condon, Westinghouse Research Laboratories; J. J. Coop, Washington College; T. D. Cope, University of Pennsylvania; J. H. Coulliette, Birmingham Southern College; E. F. Cox, Colgate University; S. W. Cram, Emporia State College; R. C. Ditto, Alma College; A. W. Duff, Worcester Polytechnic Institute; J. A. Duncan, Consolidated Edison Company of New York; D. C. Duncan, Pennsylvania State College; C. H. Dwight, University of Cincinnati; V. E. Eaton, Wesleyan University; R. L. Feldman, Roosevelt High School, Washington; A. W. Foster, University of Western Ontario; O. R. Fouts, University of Akron; M. Katherine Frehafer, Goucher College; G. S. Fulcher, Chevy Chase, Md.; Helen T. Gilroy, Beaver College; C. M. Gordon, Lafayette College; M. Grandy, University of Dayton; G. E. Grantham, Cornell University; A. N. Guthrie, Rhode Island State College; D. V. Guthrie, Louisiana State University; R. J. Havighurst, General Education Board; E. Haworth, Wilson Teachers College; S. M. Heflin, Virginia Military Institute; A. Hemmendinger, University of Oklahoma; J. R. Hobbie, Skidmore College; C. W. Hoffman, Blair Academy; W. L. Hole, Elmhurst College; R. M. Holmes, University of Vermont; F. F. Householder, University of Akron; O. Hovda, Evansville College; R. H. Howe, Denison University; L. G. Hoxton, University of Virginia; H. Hughes, Bard College; E. Hutchisson, University of Pittsburgh; A. T. Jones, Smith College; G. E. Jones, Atlantic Union College; G. E. C. Kauffman, Henry C. Conrad School; J. M. Kelley, Loyola High School, Baltimore; E. C. Kemble, Harvard University; P. E. Klopsteg, Central Scientific Company; A. A. Knowlton, Reed College; J. F. Koehler, Smith College; E. J. Kolkmeyer, Canisius College; Elizabeth R. Laird, Mount Holyoke College; K. Lark-Horovitz, Purdue University; K. G. Larson, Augustana College; H. B. Lemon, University of Chicago; T. J. Love, Georgetown University; A. Marcus, College of the City of New York; Sr. Grace Marie, College of Chestnut Hill; Louise S. McDowell, Wellesley College; A. B. Meservey, Dartmouth College; Helen A. Messenger, Hunter College; Nora M. Mohler, Smith College; Kathern Montgomery, University of Louisville; L. B. Morse, College of the City of New York; S. W. Nile, Hamilton College; W. Noll, Berea College; T. H. Osgood, University of Toledo; F. Palmer, Jr., Haverford College; C. A. Pearson, Simmons College; G. B. Pegram, Columbia University; H. A. Perkins, Trinity College; C. J. Pietenpol, Washington and Jefferson College; R. A. Porter, Syracuse University; C. H. Raynor, Roanoke College; F. K. Richtmyer, Cornell University; C. O. Riggs, Waynesburg College; D. Roller, Hunter College; G. Rosengarten, Philadelphia College of Pharmacy; G. F. Rouse, American University; H. K. Schilling, Union College; J. M. Schmidt, Hofstra College; A. R. Schmitt, Loyola University, Chicago; R. S. Shaw, College of the City of New York; F. G. Slack, Vanderbilt University; A. W. Smith, Ohio State University; L. E. Smith, Denison University; N. F. Smith, The Citadel; S. Sonkin, College of the City of New York; M. N. States, Central Scientific Company; R. J. Stephenson, University of Chicago; E. W. Thomson, U. S. Naval Academy; J. T. Tobin, Belmont Abbey College; H. Trotter, Jr., Washington and Lee University; Agnes Townsend, Barnard College; F. G. Tucker, Oberlin College; L. A. Turner, Princeton University; F. L. Verwiebe, Vanderbilt University; C. N. Warfield, Woman's College, University of North Carolina; L. R. Weber, Colorado State College; D. L. Webster, Stanford University; N. E. Wheeler, Colby College; M. W. White, Pennsylvania State College; J. G. Winans, University of Wisconsin; E. E. Witmer, University of Pennsylvania; K. S. Woodcock, Bates College; R. M. Woods, Northwestern University; A. G. Worthing, University of Pittsburgh; P. R. Yoder, Juniata College; M. W. Zemansky, College of the City of New York; C. H. Fay, University of Tulsa.

Annual Report of Treasurer

Balance brought forward from Dec. 15, 1937		$1879.58
Cash Received		
Dues received[1] for 1938	$4230.00	
Dues received for 1937	57.00	
Dues received for 1939	200.00	
Exchange charge paid	0.50	
Grant in aid	1500.00	
Donations	176.00	
Total Cash Received	$6163.50	
Total deposited from 12/15/37 to 12/15/38		6163.50
Total cash available		$8043.08
Disbursements		
Postage and supplies	$ 192.13	
Printing	70.94	
Secretary, Editor's office	450.75	
A. A. P. T. secretary's office expense	306.49	
Editor's traveling expense	75.70	
Payment to American Institute of Physics	5016.85	
Returned check	3.00	
Discount charge	1.40	
Journal survey articles	50.00	
Typewriter and equipment, Editor's office	101.56	
Total Disbursed		6268.82
Balance on hand[2] Dec. 15, 1938		$1774.26

Paul E. Klopsteg, *Treasurer*

I have audited the books of account and records of Dr. P. E. Klopsteg, Treasurer of the American Association of Physics Teachers, for the year ended December 15, 1938, and hereby certify that the foregoing statement of receipts and disbursements correctly reflects the information contained in the books of account. Receipts during the year were satisfactorily reconciled with deposits as shown on the bank statements, and all disbursements have been satisfactorily supported by vouchers or other documentary evidence.

WILLIAM J. LUBY, C.P.A.

Chicago, Illinois,
December 22, 1938.

[1] On Dec. 15, 1938 there were 846 members in good standing.
[2] A balance of approximately $400 is due the American Institute of Physics for the publication of the journal during 1938.

Report of the Secretary

The executive committee of the American Association of Physics Teachers held two meetings at Washington. Members present were F. K. Richtmyer, H. B. Lemon, P. E. Klopsteg, T. D. Cope, F. Palmer, Jr., D. L. Webster, A. A. Knowlton, A. W. Smith, D. Roller, D. M. Bennett, A. G. Worthing, K. Lark-Horovitz and R. J. Stephenson. W. L. Cheney and H. A. Barton were present by invitation.

It was voted that the financial support which the Association gives the American Institute of Physics be increased from 15 to 20 percent during 1939; this action extends for one year the increased rate authorized by the executive committee at Toronto on June 24, 1938. P. E. Klopsteg was appointed representative of the Association on the governing board of the American Institute of Physics to succeed H. L. Dodge, whose term has expired.

D. Roller was re-appointed editor of *The American Physics Teacher* for a three-year term, with a vote of commendation for his past work. J. R. Dunning and H. E. Howe were appointed associate editors.

It was voted that contributed papers, including papers read by title, will not be placed on the program for any meeting until an abstract of approximately 200 words has been received by the secretary of the Association or, in the case of sectional meetings, by the chairman of the local program committee. The manuscript for the abstract must be typewritten, double spaced, and in triplicate. Papers received by the secretary after a program has gone to press are to be read by title only.

Reports were heard from the eight special committees of the Association that served during 1938. The following committees and chairmen were requested to continue work during 1939: Physics in relation to medical education, W. E. Chamberlain; Manual of demonstration experiments, R. M. Sutton; Tests and testing, C. J. Lapp; Training of physicists for industry, P. I. Wold; Terminology, symbols and abbreviations, D. Roller and H. K. Hughes; Improving interrelations of physics and physics teaching in colleges and secondary schools, A. W. Smith; *Science Leaflet*, L. W. Taylor; Nominating committee, F. G. Slack. A special vote of approval was given to the work of the committee on a manual of demonstration experiments in producing the recently published *Demonstration Experiments in Physics*.

Petitions were received and approved for the establishment of two new chapters to be known as the Indiana Association of Physics Teachers and the Colorado-Wyoming Association of Physics Teachers; their respective representatives on the executive committee will be K. Lark-Horovitz and W. B. Pietenpol. The secretary reported that existing chapters of the Association had been asked to report the names of their officers and membership, and a condensed summary of activities during 1938 and plans for the immediate future. It was ruled that each chapter be required to submit an annual report to the secretary by December 1 and that it file an up-to-date copy of its constitution and by-laws.

Approval was given to the proposal to establish a junior membership for college and university students who have a major interest in physics and a preparation equivalent at least to two years of college physics, such junior members to have all privileges of members except those of voting and holding office. F. Palmer, Jr. and A. G. Worthing were instructed to draft appropriate amendments of Articles III and IV of the Constitution in preparation for a mail ballot to the membership.

It was voted that requests for contributions in excess of dues, and use of the terms "contributor" and "sustainer," be discontinued for the present time. The publication during 1939 of a directory of the Association was approved. The secretary was instructed to plan future ballot envelopes in such a way that the voter may be identified as a member in good standing, and that ballots which cannot be identified as coming from such a voter are to be rejected.

It was decided to hold the ninth annual meeting at Ohio State University, Columbus, in connection with the annual meeting of the A.A.A.S. Approval was also given for a summer meeting at Stanford University, California, in connection with the meeting of the Pacific Division, A.A.A.S. It was voted that the Association seek affiliation with the Pacific Division, A.A.A.S. and that P. Kirkpatrick be made the representative of the Association in that division when affiliation is completed.

The Annual Business Meeting. The annual business meeting was held at 11:45 A.M., December 30, at the National Bureau of Standards. President Richtmyer presided. The secretary reviewed the actions of the executive committee and the treasurer presented his report, which was accepted with congratulations. F. Palmer, Jr. reported on the proposal to establish a junior membership. It was voted unanimously that the By-laws be amended to include the sentence, "The annual dues of *junior members* of this Association shall be two and one-half dollars." This provision is to become effective when and if junior membership is established by amendment of the Constitution.

The results of the election of officers for 1939 were announced by R. J. Stephenson for the tellers as follows:

President: H. B. Lemon
Vice President: A. A. Knowlton
Treasurer: P. E. Klopsteg
Secretary: T. D. Cope
Members of the Executive Committee: C. J. Lapp, R. M. Sutton.

By unanimous vote, the officers of the National Bureau of Standards and the District of Columbia and Environs chapter of the Association were thanked for their services in making arrangements for the meeting.

THOMAS D. COPE, *Secretary*

Available Graduate Appointments and Facilities for Advanced Study in Physics—1939–40 (Continued)

Before attempting to make use of this information, the reader should consult the foreword to the list of 61 institutions that appeared in the December, 1938 issue, page 342.

Unless otherwise specified, the application must be filed with the person designated *before March 1;* if no person is designated, address the Head of the Department of Physics. "M only" means that the master's degree is the highest degree granted. "No form" means that a special application form is neither furnished nor required. The numerals preceding the parentheses indicate the probable number of vacancies for next year; those in parentheses indicate the total number of appointments existing in the department; e.g., 2(3) *fellows* means that three fellowships exist, two of which probably will be vacant and open to competition next year. Except where otherwise indicated, appointees do not have to pay tuition (t.) or fees (f.). Under *R* are listed fields of research that are stressed in the department and under *U*, unusual facilities for research and study.

Fordham University, Graduate Dean, New York, N. Y. Apr. 1. 2(3) *graduate assistants,* lab. asst., $600 less $100–150 t. and f. *R:* geophysics; seismology. *U:* seismic observatory.

George Washington University, Registrar, Washington, D. C. Mar. 15. ?(2) *teaching fellows,* elem. teach., $600 less $16. Work for doctorate limited at present to theoretical physics.

Harvard University, Cambridge, Mass. 4(many) *half-time instructors,* teach., $900 to $1000 less $200 t.; 2(4) *half-time assistants,* teach., $900 less $200 t.; 5(7) *fellows* and *scholars,* $500 to $900 less $400 t. For fellowships and scholarships apply on form before Mar. 1 to Dean of Graduate School of Arts and Science; for other appointments apply by letter immediately to Chairman of Department. *U:* high pressures; electric oscillations; spectroscopy; cosmic rays; mass spectrography; ionosphere studies; acoustics.

Haverford College, Haverford, Pa. M only. No graduate appointments available for 1939–40.

Johns Hopkins University, Baltimore, Md. 5(8) *junior instructors,* 2 hr/wk conference, 2 periods/wk lab. asst., $600 less $336 t. and f.; 3 *laboratory assistants,* 2 periods/wk asst., remission of $336 t. and f.; 5(5) *university scholars,* remission of $300 t. but not $36 f. For scholarships apply on form supplied by Registrar's Office; for other appointments, by letter to Prof. J. C. Hubbard. *R:*optics; vacuum, visible, and infra-red spectroscopy; atomic and molecular structure; x-rays; nuclear physics; supersonics; theoretical physics.

Kansas State College, Prof. A. B. Cardwell, Manhatten, Kan. M only; Apr. 1; no form. ?(4) *graduate assistants,* lab. teach., $450 less $50 t. and f. *R:* applied spectroscopy; x-rays; electron emission.

Lafayette College, Prof. C. McC. Gordon, Easton, Pa. M only; no form. 2(2) *assistants,* lab. and lec. asst., grading, $400 and room. *R:* electronics; radio; short waves; mathematical physics.

Missouri School of Mines, Rolla, Missouri. M only. No graduate appointments available at present time.

Oberlin College, Dean E. F. Wittke, Oberlin, O. M only; Mar. 15. 1(1) *graduate scholar,* $300. *R:* soft and hard x-rays; certain fields of thermionics; spectroscopy. *U:* soft x-rays.

Ohio Wesleyan University, Prof. C. W. Jarvis, Delaware, O. M only; May 1; no form. 0–1(1) *graduate assistant,* lab. asst. and research, $200 less about $25 f. *R:* limited work in thermionics and spectral excitation by impact.

Oklahoma Agricultural and Mechanical College, Stillwater, Okla. M only. 3(4) *graduate assistants,* teach quiz or lab. sections, $450.

Rensselaer Polytechnic Institute, Chairman of Graduate Committee, Troy, N. Y. 1–2(1–3) *fellows,* 6 credit hrs/wk service *may* be requested, $900 less $300 t. and f.; ?(?) *scholars,* study and research, $100 to $300, less $300 t. and f. *R:* optics; acoustics; radio and communication; properties of metals.

Rice Institute, Prof. H. A. Wilson, Houston, Tex. Apr. 1; no form. 5 *fellows,* 2 afternoons/wk asst., $500 less $34 f. *R:*nuclear physics; photoelectric conductivity; magnetic properties; etc.

St. Louis University, Dean Thurber M. Smith, St. Louis, Mo. Mar. 15. 1(2) *graduate fellows,* conduct lab. and quiz sections, $350 to $400. *R:* photoelectricity; kinetic theory; spectroscopy; scattering in gases, photography, etc.

Teachers College, Columbia University, Prof. S. R. Powers, New York, N. Y. Apply any time; no form. 1(1) *graduate assistant,* physical science lab., grading, educational research, etc., $1000 less $20 f.; (1) *graduate assistant,* physical and biological science lab. and demonstrations, etc., $500 less $12.50 per point t. and $5-10 f. *R:* science teaching and science education.

Tufts College, Prof. J. R. Harrison, Medford, Mass. May 1; M only; no form. 0(2) *assistants,* lab. asst., $1000 less $5 f. *U:* vacuum tubes; piezoelectricity.

Tulane University, Prof. D. S. Elliott, New Orleans, La. M only; Apr. 15; no form. 3(4) *graduate assistants,* 10 hr/wk lab. teach., $500 less $25 f. *R:* electronics; photoelectricity; photoelectric spectrophotometry; infra-red spectroscopy; x-ray crystal analysis.

Union College, Prof. P. I. Wold, Schenectady, N. Y. M only; May 1; no form. 1(2) *graduate assistants,* lab. asst., $600 less $90 t. and f. *R:* properties of metals; vacuum tube circuits.

University of Akron, Prof. F. F. Householder, Akron, O. M only; May 1; no form. 1–2(2) *graduate assistants,* 15 hr/wk lab. asst., grading, $450 less $2 f./credit hr.

University of Alabama, University, Ala. M only. No graduate appointments available for 1939–40. *R:* x-rays optics.

University of Arizona, Graduate Dean, Tucson, Ariz. M only. 1(1–2) *fellows,* lab. asst., $350 less $54 t. and f. *R:* x-ray diffraction patterns; solar radiation (spherical absorber). *U:* astrophysics; photoelectric and photographic photometry with 36-in. reflector.

University of Arkansas, Prof. L. B. Ham, Fayetteville, Ark. May 1; M only; no form. 1–2(4) *graduate assistants*, grading, apparatus, $10 to $20/mo. less t. and f. *R:* sound and related problems.

University of Colorado, Boulder, Colo. Apply any time. 1–3 *graduate assistants*, lab. and class asst., $450 to $600 less $79.50 t. and f.; 1 *research fellow*, study and research, $500; 1–2 *university fellows*, study and research, $200; 1–2 *scholars*, study and research, remission of t. and physics f. For assistantships apply to Prof. W. B. Pietenpol; for other appointments, to Graduate Dean.

University of Denver, Dean A. C. Nelson, Denver, Colo. M only; May 1. 1–2(1–2) *graduate assistants*, lab. and research asst., $125 to $250 less $225–235 t. and f. *U:* high altitude laboratory (14,000 ft); cosmic rays.

University of Florida, Prof. R. C. Williamson, Gainesville, Fla. May 1; M only. 1 *graduate assistant*, lab. asst., $450 less $30 f.

University of Idaho, Prof. G. W. Hammar, Moscow, Idaho. Apr. 15; M only; no form. 1(2) *teaching fellow*, teach. and lab. asst., $500. *R:* various fields. *U:* optical spectroscopy.

University of Kentucky, Prof. Wm. S. Webb, Lexington, Ky. May 15; no form. 8(8) *graduate assistants*, 10 hr/wk lab. asst., $500 less $106 t. and f.

University of Louisville, Louisville, Ky. M only. No graduate appointments available at present time.

University of Manitoba, Winnipeg, Manitoba, Can. No appointments available in 1939–40. *R:* biophysics; thermionics; x-rays; radioactivity. *U:* Cancer research laboratory, with 1 gm of radium, half in needles and half in solution.

University of Maryland, Prof. Chas. G. Eichlin, Baltimore, Md. M only; June 1; no form. 2 *fellows*, 9 hr/wk lab. teach., $400.

University of Mississippi, Dean D. H. Bishop, University, Miss. M only; July 1. 1(1) *graduate scholar*, teach. and lab. asst., $300 less $50.75 t. and f. for state residents or $100.75 for nonresidents. Applicants interested in a particular research field should describe their preparation for it.

University of New Mexico. M only; last date for application indefinite. 1(1) *graduate fellow*, lab. teach., $400 less $62 t. and f. *R:* geophysics. *U:* lightning and thunderstorm phenomena.

University of Toronto, Toronto, Can. No form. 9(9) *assistant demonstrators*, 13–14 hr/wk lab. asst., $500 less $75 t. and f. *R:* low temperatures; spectroscopy; geophysics; meteorology; thermionics; x-rays. *U:* liquid hydrogen and helium; hyperfine structure in spectroscopy; electron microscope.

University of Utah, Salt Lake City, Utah. M only. 1(3) *teaching fellows*, 15 hr/wk lab. asst., $300 less t. and f.

University of Virginia, University Station, Charlottesville, Va. 2(5) *service fellows*, lab. and quiz sections, $485 to $655; 1(2) *service fellows*, lab. and quiz sections, $368 to $470; 2(2) *Philip Francis duPont junior fellows*, $128; 1(2) *Philip Francis duPont senior fellows*, $278; 1(1) *Philip Francis duPont research fellow*, $550 to $750. For service fellowships apply to Prof. L. G. Hoxton; for duPont fellowships, which involve research and study only, apply to Secretary of Graduate Dean. *U:* ultra-centrifuge problems.

Recent Publications and Teaching Aids

First-Year and Intermediate Textbooks

Physics for Technical Students in Colleges and Universities. Ed. 3. William Ballantyne Anderson, Professor of Physics, Oregon State College. 818 p., 534 fig., 15×23 cm. *McGraw-Hill*, $4. In this issue of the third edition of the author's *Physics for Technical Students* [Am. Phys. Teacher **6**, 107 (1938)], the two volumes are bound together in a single cover.

Household Physics. Madalyn Avery, Assistant Professor of Physics, Kansas State College of Agriculture and Applied Physics. 454 p., 378 fig., 14×20 cm. *Macmillan*, $3.50. The one-semester college course provided by this text aims to present the fundamentals of physics so as to show their close relationships to the problems of the modern home and also so as to provide a background for the various commercial fields which home economic students enter. Subject matter has been selected that has proved to be of value and interest to the many students who have taken the course at Kansas State College during the past ten years. Although the mathematics has been kept simple, quantitative as well as qualitative questions are included with most of the chapters.

College Physics. Henry A. Perkins, Professor of Physics, Trinity College. 829 p., 622 fig. and plates, 29 tables, 15×23 cm. *Prentice-Hall*, $3.75. The chief aims in this elementary text are to emphasize principles rather than phenomena, to treat difficult topics more fully and with less evasion of the difficulties involved than is usual in elementary texts, and to introduce modern physical ideas as well as the necessary classical aspects whenever they can be discussed with some degree of rigor. The author believes that textbook discussions should be so understandable and relatively complete that the instructor can spend the class time, not in explaining explanations, but in enlarging on the text, citing illustrations and applications, and performing experiments. Mathematics through trigonometry is used freely.

Introduction to Physiological Optics. James P. C. Southall, Professor of Physics, Columbia University. 463 p., 135 fig., 8 tables, 15×23 cm. *Oxford Univ. Press*, $5.50. The aim of the author has been to provide a trustworthy general introduction to physiological optics that will be useful both to intelligent laymen interested in the dioptics of the eye and the sense of sight and to specialists

in physics, biophysics, physiology, psychology, opthalmology and illuminating engineering. The material has been compiled from a course of lectures for undergraduates which the author has given for many years. The plan and scope of the work are well indicated by the chapter titles: The organ of vision; Optical system of the eye; Correction eye-glasses; Hyperopia, myopia, and astigmatism; Movements of the eyeball in its socket; Nature of binocular vision; Rod vision and cone vision; Color vision and colorimetry; Theories of color vision; and Temporal and spatial reactions of the organ of vision.

Fundamentals of Electricity and Magnetism. Ed. 2. LEONARD B. LOEB, Professor of Physics, University of California. 578 p., 224 fig., 15×23 cm. *Wiley*, $4.00. The general plan used in the 1930 edition of this text has not been altered materially, the purpose still being to provide students of the sciences and engineering with a one-semester course in the fundamental elements of electricity and magnetism, given either as part of a two-year sequence in general physics or as an intermediate course to follow a briefer general course. Many parts of the treatment have been revised or augmented, however. The chapters on potential differences, electromagnetics, electromagnetic induction and the basic concepts of alternating currents have been almost completely rewritten. The discussion of units and dimensions has been revised and augmented in the light of the articles by Birge and others in *The American Physics Teacher*. Measurements of capacitance and self-inductance are now included in the discussion of electrical measurements. Among the many minor alterations and extensions made to modernize and extend the usefulness of the text are the addition of material on the van de Graaff generator, the molecular character of dielectric action, new devices for achieving nuclear transformations, and the G-M photoelectric counter. The problems have been revised. Elementary calculus is employed throughout the text.

ADVANCED TEXTBOOKS AND REFERENCES

A Manual of Radioactivity. GEORGE HEVESY, University of Copenhagen, AND F. A. PANETH, Imperial College of Science and Technology, London. Ed. 2. Tr. by Robert W. Lawson, 322 p., 54 fig., 56 tables, 15×24 cm. *Oxford Univ. Press*, $5.50. The present edition of this textbook is an English translation, brought up-to-date, of the revised and enlarged German edition of 1931. The treatment is modern and comprehensive, dealing not only with the physical side of radioactivity but with its chemical aspects and relations to bordering sciences. References are given but are confined to treatises, review articles, and a few important individual papers; to give a complete list of references even to recent work would require considerable space, for in 1936 alone, as the authors point out, some 1200 papers on radioactivity appeared.

Atomic Spectra and the Vector Model. A. C. CANDLER, Sometime Scholar of Trinity College, Cambridge. Vol. I, *Series Spectra*, 245 p., 142 fig., 4 plates, 1 table; Vol. II, *Complex Spectra*, 281 p., 212 fig., 4 plates, 14×21 cm. *Cambridge Univ. Press* and *Macmillan*, $8.50 per set. In these two volumes the modern notation adopted as standard in 1929 is used to present the work of Fowler's *Report* and Hund's *Linienspektren*, two references that are essential to the understanding of modern spectroscopy but that make use of the old cumbrous and outmoded notation. There are also chapters on the splitting of spectral lines in a magnetic field, hyperfine structure, quadripole radiation and fluorescent crystals. The vector model has been used throughout the treatment.

Advanced Experiments in Practical Physics. C. E. CALTHROP, Senior Lecturer in Physics, Queen Mary College, University of London. 140 p., 170 fig., 2 plates, 14×22 cm. *William Heinemann* (London), 8/6d. Forty-eight intermediate and advanced experiments on properties of matter, heat, light and electricity are described in this manual. Emphasis is placed on practice in physical technics, the full use of graphical methods for the representation of results, and the use and design of relatively simple and inexpensive apparatus. The instruments of precision required for some of the experiments are those that are likely to be found in any well-equipped laboratory. The requisite theory has been kept to a minimum. A number of the experiments are original or are adapted from periodical articles. Two of them—on the temperature variation of Young's modulus and on the electromagnetic pendulum—were described by the author and J. T. Miller in this journal [Am. Phys. Teacher **3**, 131, 32 (1935)].

Textbook of Thermodynamics. PAUL S. EPSTEIN, Professor of Theoretical Physics, California Institute of Technology. 418 p., 64 fig., 61 tables, 15×23 cm. *Wiley*, $5. The arrangement of this text is such that one-half of it provides a basic course in thermodynamics for seniors and beginning graduate students, while the other half serves as a reference or for special courses of a more advanced character. The material in this latter half demonstrates beautifully the power and wide range of the thermodynamic method, for it covers so wide a variety of problems as equilibrium of binary systems, fugacities and activities, the capillary layer, degenerate perfect gases, electron and ion clouds, theory of specific heats, equilibrium involving radiation, and magnetic and electric phenomena. The whole treatment is from the point of view of the physicist; such an approach, as the author points out, does not lie, primarily, in the exclusion or inclusion of chemical applications, but in the detailed, careful, and reasonably rigorous treatment of fundamental concepts and an emphasis on the main applications to physical problems. The discussion of the history of the first law is original and illuminating.

DIGEST OF PERIODICAL LITERATURE

Apparatus and Demonstrations

Wide range motor speed control. O. H. Schmitt; *J. Sci. Inst.* **15**, 303, Sept., 1938. By reconnecting in series the armature and field coils of a small, shunt-wound motor and adding a slide potentiometer as shown in Fig. 1, the

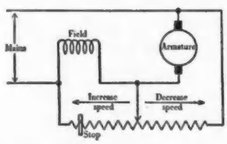


Fig. 1. Wide range motor speed control.

speed of the motor may be varied smoothly over a wide range. Moving the potentiometer contact to the right reduces the motor speed to zero by increasing the field and decreasing the armature voltage. The potentiometer should have about the same total resistance as that of the motor operating normally at full load, and should be fitted with a stop to prevent the armature speed from accidently becoming excessive. This method of speed regulation, while wasteful of power, has two advantages: stable operation over a ratio of speeds of 100 to 1; and exceptionally good regulation at low speeds because of the dynamic braking action of the strong field and the low armature shunt impedance of the potentiometer.—H. N. O.

Apparatus for spectroscopic analysis. E. E. Chandler; *J. Chem. Ed.* **15**, 544, Nov., 1938. A long stemmed funnel *a* (Fig. 1) is bent at *b* and the lower end *c* is flared out. The solution, which also contains hydrochloric acid, heaps itself up at *d*, so that a sufficient supply is present to steady the spark, and prevent it from contacting and perhaps breaking the container. The slit of the spectroscope should be placed far enough behind the spark *e* to prevent corrosion of the spectroscope metal. The old solution is removed, and the platinum electrode *f* cleaned, by running acidulated water from a reservoir, not shown, through the funnel. Manganese, zinc, barium, strontium, calcium, magnesium, sodium and potassium can be detected, even in the presence of one another. Any acidulated boron compound is revealed with certainty.—D. R.

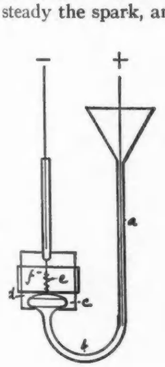


Fig. 1.

A projection electroscope for α- and β-rays. B. A. Spicer; *J. Sci. Inst.* **15**, 336, Oct., 1938. This projection electroscope (Fig. 1) consists of two parts rigidly fastened to a wooden base: (1) the electroscope with ionization chamber and optical projection system; and (2) an adjustable holder for α- or β-particle sources.

The gold leaf system comprises a brass rod *A* with attached gold leaf, connected by a horizontal brass rod to a brass plate *B* in the ionization chamber. The compound bush *C* of sulfur and ebonite provides insulation from the outer case. The system is charged by means of the wire *F* which can be brought into contact with the insulated terminal *H* and the gold leaf system by rotation of the brass rod *E*. The rod *E* passes through a metallic bearing in the ebonite disk *D* and is turned by the insulated handle *G*. To *H* is connected one pole of a 150–200-v dry battery, the other pole being grounded. A spring returns *F* to its original position when *G* is released. For use with α-particles the ionization chamber is fitted with a removable cover *J* having a wire gauze face. With β-particle sources a much deeper cover with an aluminum face 0.05 mm thick is used. The slots *T* are for aluminum filters, to show β-particle absorption. The position of the projection system is indicated by the dotted circle.

The source holder has a slide movement, operated by the handwheel *K*, and a centimeter scale *L*; the movement may be traversed in the supporting head *M* and fixed by a set screw. Sources are inserted in the orifice *S* and held by the spring *N*. For α-particle range demonstrations a deposit of Ra F (polonium) shown at *O* is used, and a stop *P* is so placed that all rays emerging from *P* enter the ionization chamber at the greatest distance at which observations are made. The time of fall of the gold leaf over a given distance is observed for increasing distances of the source from the wire gauze. The rate of fall rises to a maximum and then falls sharply to an insignificant value; the point at which this sharp downward slope, produced, cuts the axis gives the α-particle range. For a β-particle source a thin layer of powdered glass containing a deposit

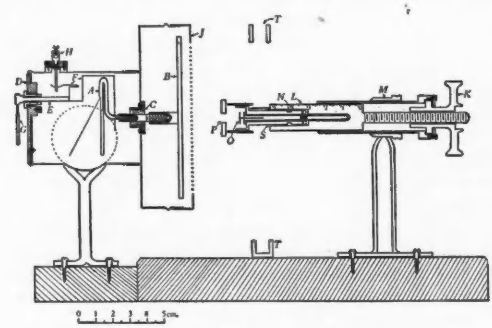


Fig. 1. Projection electroscope for α- and β-particles.

of Ra D is cemented to the container and covered with a protective face of thin aluminum.—H. N. O.

Drilling and tapping Bakelite. Anon.; *Shop and Lab.* **1,** No. 5, 8, Apr., 1937. The drilling and tapping of Bakelite is hard on milling cutters, drills, and taps; moreover, it is difficult to get good threads and clean small-size holes. But if carbon tetrachloride is used as a cutting lubricant, drilling and tapping both sheet and molded Bakelite is greatly facilitated. One can tap 8–32 holes in $\frac{1}{4}$-in. laminated stock at a relatively high speed without stripping threads or producing ragged edges when the tap is kept moist with the carbon tetrachloride.—D. R.

Physics in Industry

Facilities for physics students in industry during vacation. Anon.; *J. Sci. Inst.* **15**, 388, Nov., 1938. The Institute of Physics (London) has been markedly successful in its efforts [Am. Phys. Teacher **6**, 52 (1938)] to place students during vacations in English laboratories where they can gain first-hand experience in the application of physics to industrial problems. In 1938, 19 firms, 9 research associations, and 3 government agencies offered such facilities and 14 students availed themselves of the opportunities provided. A problem yet unsolved is how to enable students of limited means to gain experience in laboratories too far away for them to be able to live at home.—D. R.

Physics of the Automobile

Optics of headlights. J. H. Nelson; *J. Sci. Inst.* **15**, 318–322, Oct., 1938. For mass production an automobile headlight must be simple in design, consisting essentially of an inexpensive and readily accessible bulb, a reflector which can be made from a metal pressing, and a front glass. For open-road driving, 36-w tungsten filament bulbs are generally used.

The main factors in the design of the reflector are the aperture and the angle of collection. For distant illumination the aperture should be as large as possible. With the aperture fixed, there is a series of possible parabolic reflectors between the two extremes shown in Fig. 1. A short focus reflector, (*a*), collects a larger part of the available light, while one of long focus, (*b*), because of the finite size of the source, gives greater beam concentration. Neither extreme is satisfactory and a compromise is made. Fresnel showed theoretically that, for a spherical transparent source, the semi-angle of collection giving the best projection from a particular size of aperture is 126°, while if the reflecting area is fixed, the best angle is 108°. He also showed that the projector efficiency has a flat maximum at 126°, being only 4 percent less at 108°. In nearly all automobile reflectors the semi-angle is between 108° and 126°, the larger lamps having slightly larger angles to keep the vertical beam spread within desirable limits.

While the reflector concentrates the light for distribution, the front glass affects that distribution. The problem

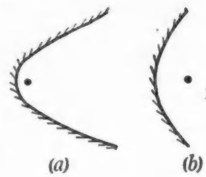


Fig. 1. Extreme cases of parabolic reflectors.

here has been to develop a glass that combines a beam of high axial candlepower, for distant illumination, with a diffused broad beam, for near illumination. In one type used in England and Germany, the center is a horseshoe design of prismatic lenses, which distribute the light over a wide angle in and below the horizontal plane, and the outer annulus is composed of negative cylindrical lenses, which give a small, graded spread to the main beam. A fluted glass type used in America gives a similar distribution. The width of the flutes is constant over the whole glass but the glass is divided into different regions by horizontal and vertical lines; in these regions the power of the flutes varies, those of higher power being toward the center. In designing glass, the aim is to give such a distribution of light in a horizontal plane that, when isofoot-candle lines are drawn, one such line will approximately fit the road.

To replace the main beam by an antidazzle beam when automobiles meet, three principal systems are in use. (1) The Bilux or Lucas-Graves system, compulsory in Germany and France and used on some commercial vehicles in England, employs an auxiliary filament placed on the axis of the reflector in front of its focal point and supported by a small metal shield which stops all light given out below the horizontal plane; since only the top half of the reflector is illuminated, the beam is "flat-topped," with most of the light below the horizontal plane. This auxiliary axial filament also gives a desirable spread of light in the plane of the road. (2) In the Lucas "dip and switch" system, used generally in England, the offside lamp is extinguished and the near side beam simultaneously deflected 4° downward and toward the near side; no special bulb is needed but an arrangement for tipping one reflector is required. (3) In the twin-filament system, used in America and to some extent in England, one filament is displaced from the focal point to deflect the beam downwards, or sideways and downwards. The bulb is less complicated than the Lucas-Graves bulb. This system reduces glare, but is unsatisfactory except in low power lamps.

There is no filter that, placed in front of a lamp, will improve its fog penetrating power. A lamp for use in fog should emit as little light as possible above the horizontal. It is especially necessary that the candlepower at large angles to the horizontal be reduced to the minimum. Differences of opinion exist as to the most suitable beam for fogs but the tendency is toward wide beams. The most suitable width, in the author's opinion, would be between 60° and 80°, although many lamps in use have a spread of 80° to 120°.—H. N. O.